C. W. Dilke Esq.
with the Author's kind regards
Sept. 30th 1851 -

ON THE

CONSTRUCTION OF THE BUILDING

FOR THE

EXHIBITION

OF THE

WORKS OF INDUSTRY OF ALL NATIONS,

IN 1851.

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BY MATTHEW DIGBY WYATT, ASSOC. INST. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EXCERPT MINUTES OF PROCEEDINGS, VOL. X.
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INSTITUTION OF CIVIL ENGINEERS.

January 14, 1851.

WILLIAM CUBITT, President, in the Chair.

No. 843.—" On the Construction of the Building for the Exhibition of the Works of Industry of all Nations in 1851." By Matthew Digby Wyatt, Assoc. Inst. C. E.*

The first attempt to concentrate, within the compass of a few acres, material for forming a comprehensive idea of the industry of all nations, has been declared to be a great experiment, worthy of being tried, upon a scale commensurate with the industrial resources of this country. It will be admitted, that the immediate success of any such experiment must be directly proportioned to the perfection of the apparatus employed, and that, in attaining perfection in the construction of any great apparatus, three essential conditions are demanded : 1st. A just apprehension of the results to be produced ; 2ndly. A well-digested scheme for producing the results aimed at ; and 3rdly. Power and dexterity to arrange the whole, so as to insure the perfect accordance and working of all its parts, in the simplest and best manner.

The building must be regarded as the principal physical apparatus, by means of which this great experiment is to be tried, and in order to form some idea of its structural fitness, it is necessary to ascertain how far those connected with the work have understood and fulfilled their duty, in relation to these three essential conditions of success. It may be well, therefore, to consider, 1st. The results to be produced, or, in other words, the requisites of the building ; 2ndly. The scheme for producing the results aimed at, or, in other words, the design of the building ; 3rdly. The power and dexterity with which the scheme has been realized, or, in other words, the construction of the building.

Beginning, therefore, with

The Requisites of the Building,

it must be manifest, that as the first conditions of the Exhibition of 1851 differed, in many essential particulars, from those of all ante-

* The discussion upon this paper extended over a portion of three evenings, but an abstract of the whole is given consecutively.

cedent exhibitions, a recurrence to precedent was, to a great extent, precluded. Yet the study of previous arrangements, although not affording models for imitation, has proved serviceable, in enabling a knowledge to be obtained, of the difficulties which seemed most likely to increase in proportion to the expansion of scale.

From the French Exhibition of 1849 many hints were obtained, and a reference to the published plan of the building for that exhibition* will suffice to demonstrate their nature.

The length of some of the stalls, which occasioned a difficulty in passing speedily from one point to another, and the shortness of others, which confused the spectator, by tempting him to diverge from a steady course, demonstrated the necessity for some arrangement by which it should be possible to examine the whole exhibition, by following a simple, and therefore easily remembered, system throughout; and, at the same time, to find and reach with facility any particular object.

A square enclosed by long galleries was objectionable, as it lessened the apparent vastness of the building, since from no one point could the dimensions of more than one quarter of its extent be perceived.

The building erected by the King of Bavaria at Munich, expressly for periodical exhibitions of national works of industry, is a noble structure, but its academic plan, dividing it into regular halls and chambers, while ministering to architectural proportion, diminishes the apparent extent, and increases the difficulty of arrangement, by assigning limited dimensions of space to certain groups of objects, the amount of which, varying with every exhibition, necessarily requires compressing at one time, in order to bring the series of objects within the limits of the apartment allotted to them, or spreading out at another, in an attempt to cover space they may be insufficient to fill. The massive character and great cost of the "Industrie Gebäude," still further precluded the possibility of its being adopted as a precedent.

The noble hall of the Kroll's Garten, at Berlin, in which the last Prussian exhibition was held, was certainly well adapted for its purpose, and bore testimony to the value of simplicity of plan, an element of success found wanting in the plans of the Academy and of the Arsenal at Berlin, in which accommodation had been provided for the previous exhibitions of the industry of the Zollverein.

* *Vide* "A Report on the Eleventh French Exposition of the Products of Industry, prepared by the direction of, and submitted to the President and Council of the Society of Arts." By M. Digby Wyatt. Folio, plates. Lond. 1849.

The arrangements of the various displays of works of industry, which had taken place in the apartments of the Royal Irish Society, at Dublin; in the rooms of the Society of Arts, and in Covent Garden Theatre, in London; at Edinburgh, Birmingham, Manchester, and in other places, were valuable, chiefly as having practised exhibitors and others in the tasteful combination of objects of beauty and utility.

A feeling that the complete novelty in the conditions of a cosmopolitan exhibition demanded an original method of treatment, perfectly different from any previous attempts, materially influenced the production of that invitation to the world at large, to contribute suggestions for the building, which was issued on the 13th March, 1850, by the Members of the Building Committee, whose zeal and liberality in giving the benefit of their talents and technical knowledge to the public, on that occasion, cannot but reflect equal credit on themselves and on the professions to which they belong.

The response to the invitation of the Building Committee was remarkable, as producing contributions from upwards of two hundred and forty competitors for honour only. The value and beauty of many of the schemes thus elicited, and the wildness of others, must have been apparent to the public, and to the members of the Institution of Civil Engineers, in whose theatre they were exhibited by the permission of the Council.

The task of analysing the systems proposed was a laborious one, and involved the devotion of much time and thought, to thoroughly examine into the different principles upon which the plans appeared to be based; the effort, however, was by no means profitless, since it contributed to a recognition of the value of the various requisites, the satisfactory supply of which, in a building constructed to effect an untried purpose, could not but constitute one of the most important merits of such a structure.

Principles of the Proposed Plans.

The principle of arrangement, by which it was necessary that the stalls should run longitudinally, appeared defective, on account either of the inconvenient length of the stalls, if there were only few transverse divisions, or their great confusion, if intersected by many. Plans on radiating systems crowded the public in counter currents upon the foci, and could scarcely be adapted to the form of the site. Plans of an architectural character were generally too monumental, too much divided, and far too expensive, involving an excess of walling, exactly proportioned to the amount of their sub-

division, and rendering proper supervision almost impossible. Plans dividing the building into four distinct exhibitions were objectionable, as the effect of the whole would have been marred, a quadruple staff of superintendents would have been necessary, and one part would have been crowded whilst another was empty, in consequence of the impossibility of accurately predetermining the proportion of space to be allotted to each section ; whilst the disproportionate areas of the spaces demanded for raw products, machinery, manufactures, and fine arts could only have produced an irregular building. Plans showing the whole site covered over with parallel sheds, with spaces between, would have involved great lengths of unnecessary inclosure, were likely to be monotonous, and were devoid of any charm of variety, or grandeur. While from some designs, the lesson was learnt, of what to avoid, from others much information was gained, since many indispensable requisites had been foreseen, and more, or less ingeniously provided for, in the plans submitted by the competitors.

Description of the Site.

As the principles which were first laid down were, to a great extent, dictated by the form and character of the ground, it may be well to premise, that the site consists of a piece of ground, originally pointed out by His Royal Highness Prince Albert, on the occasion of the first private meeting on the subject of the Exhibition, held at Buckingham Palace on the 30th June, 1849, as affording advantages which few other places might be found to possess. It contains about 26 acres, and is of a form nearly approaching that of a parallelogram, of which the sides are as one to four nearly, being 2,300 feet long by 500 feet broad (measured on the central axes), fronting north and south, and having its ends east and west, with an almost uniform fall of about one in two hundred and eighty, from west to east. Several large trees stretch about half across the centre of its length, and two clumps of smaller trees, which it was indispensable to preserve, stand near the northern boundary on the east and west of the central group. Such being the site, and the broad outline of the nature of the Exhibition having been determined, the following requisites for the arrangement of the plan gradually developed themselves, and will be found to have been provided for in the present building.

Requisites finally Assumed.

First, that a main avenue of ample width should extend the whole length from east to west, as near the centre of the structure as the

trees would permit; that this avenue should be higher than any other parts of the building, with the exception of a transverse avenue ranging with it in height, leading from the southern entrance, and crossing the entire structure at right angles, as near the centre as possible.

Secondly, that limiting the number of entrances to one at the eastern, one at the western, and one at the southern end of the main avenues, would be convenient to the public, and simplify the supervision of the money-taking, &c., but that it would be desirable to provide numerous exits. That of these three entrances the southern would be the most important, and the one about which it would be best to group the executive offices.

Thirdly, that other longitudinal avenues should extend from north to south, and that transverse gangways between the stalls, numbered to correspond with the Catalogue, should connect them with the main longitudinal avenue, so that any visitor, by passing down one side of a gangway, and up another, or down the centre of one gangway, and up the centre of another, and taking the gangways regularly one after another, might be likely not to omit any portion of the Exhibition, and not to see any part of it twice over; or so that any visitor, desirous of proceeding directly to a particular object, might be able to pass along the main, or central avenue, until he arrived at the gangway (marked to correspond with the indications of the Catalogue), which would be sure to lead him to the object he was in search of; and so that, in either case, the disposition of the building might rather direct than coerce the motions of the visitors, and might insure the general movement of the public in regular currents.

Fourthly, that round and about the three clumps of trees would be the most convenient spots for the refreshment rooms.

Fifthly, that a fixed dimension of 24 feet should be adopted; which should serve as the basis of all rectangular lines parallel to the main avenues, on plan; and that the whole of the supports for the roofing should be placed either at their intersection, or at the intersection of multiples of them; that the mistakes and consequent delay attending the adoption of irregular dimensions would be thus avoided;—that the lines of the Building would be rendered agreeable;—that uniform areas of roofing could be conveniently arranged for drainage through the hollow columns; and that, to use the common phrase, "the work would run off all the better for it."

Sixthly, that omitting all internal enclosures, or divisions, excepting those formed by the stalls, would have the good effects of allowing the eye to range at liberty, and to appreciate the extent, and

the vistas of the building—would afford facilities for any mode of arrangement best calculated for displaying the goods, and for the adoption of any system of classification—leaving the hands of the Executive unfettered;—would facilitate the police and general supervision—and last, not least, would save a large sum of money.

Many other requisites for the kind of structure likely to be most desirable, such, for instance as that it must be thoroughly lighted, ventilated, drained, built simply, economically, and with a view to ultimate value, are of so self-evident a character, that, to dwell upon them in detail, would uselessly delay the consideration of the second part of the subject "an examination of the precise mode in which the requisites are supplied in,

The Design of the Present Building.

After much deliberation, what were considered the best means of supplying these requisites were embodied in a series of drawings, and tenders were invited by advertisement on the 12th June, 1850. The public were, at the same time, given to understand, that proposals for "methods of construction other than those shown upon the drawings would be entertained," if made in a bonâ fide form. The reliance thus manifested in the probability of the urgency of the demand calling forth valuable suggestions from practical men, was by no means misplaced,—since it had the effect of stimulating Mr. Paxton to consider the subject with his usual ability and energy, giving it the benefit of his great experience in the construction of buildings of a somewhat analogous character. All that gentleman's endeavours to supply new remedies for old defects in structures of glass, to combat the prejudices of conventional construction, and to develop the capabilities of the combination of glass, wood, and iron, have been so recently and so ably described by himself, in other places, that it would be needless here to do more than to refer to them in general terms.

All his efforts must, however, be looked upon as so many experiments, tried as if for the purpose of enabling England, on this occasion, to exhibit to foreign nations some novel and admirable mechanical appliances, and a fine specimen of the resources she possesses, in the energy of her individual citizens—the true source of her wealth, and the key to her industrial position.

It was alike fortunate for the Royal Commissioners—and for Mr. Paxton, that Messrs. Fox, Henderson, & Co. should have been interested in carrying out the undertaking. From the practical experience which they brought to bear upon the subject, designs grew into realities,—difficulties were foreseen and remedied,—and a

high order of mechanical contrivance was displayed, in adaptations of machinery to economise labour and to perfect production.

The Area covered.

The building, as now erected, provides an area, upon the ground floor, equal to 772,784 square feet, and upon the level of the galleries, 23 feet from the floor, an area equal to 217,100 square feet, making a total area of available space of 989,884 square feet.

The General Features of the Design.

The combination upon so vast a scale, of the materials, glass, wood, and iron, of which alone the building is constructed, and the care, which has been taken, not to exaggerate the proportions of form in which those materials may be best and most economically used, will probably tend to counteract conventionality of style in architecture, and may be expected to produce, hereafter, important changes, alike in the construction and appearance, of many extensive buildings throughout the country.

The general distribution of the design recalls the system of a cathedral structure—a vast nave 72 feet wide, rises to a height of 64 feet above the soil. This is crossed by a transept 408 feet long, equally wide and lofty; but with the difference, that it is crowned by a waggon vault, increasing its height to 104 feet at the centre.

On each side of the nave and transept, a series of aisles, 24 feet wide, by 44 feet and 24 feet high, spread out to a total width of 456 feet.

Some idea may be formed of the leading peculiarities of the building, by recalling the fact, that its main avenue, between the columns, is nearly double the width of the nave of St. Paul's Cathedral, while its length is more than four times as great. The walls of St. Paul's are 14 feet thick, those of the Hyde Park Building are 8 inches. St. Paul's required thirty-five years to erect, the building will be finished in about half that number of weeks.

The Drainage.

It may be conceived, that the arrangements for carrying off, rapidly, the entire roof-water of 17¾ acres, involved considerable preparation. Six rows of cast-iron pipes, each 6 inches diameter, communicating with the hollow columns, supporting the roof, follow the fall of the ground from west to east, and convey the water to three drains running north and south. The latter, communicating with sewers running east and west, outside the building, convey the water to the lowest points, at the east end of the site, from which it

is discharged into the main sewer in the Kensington Road, by an egg-shaped culvert of 4 feet 8 inches sectional area. A datum line having been assumed, the level of the flooring of the whole area was arranged to incline 1 inch in 24 feet, approximating to the fall of the ground.

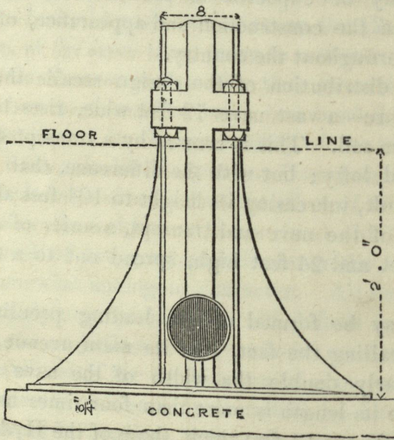
The Flooring.

The floor was arranged to consist of boards $1\frac{1}{2}$ inch thick, laid half-an-inch apart, upon joists 7 inches by $2\frac{1}{2}$ inches, bearing upon sleepers 13 inches by $3\frac{1}{4}$ inches, at intervals of 8 feet apart.

The interstices were left between the boards to permit the passage of dust and dirt. This method of flooring has been found to answer well at Chatsworth and in other localities.

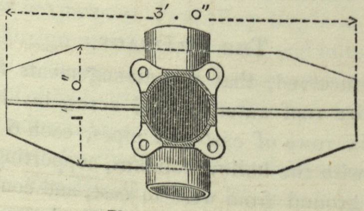
The Foundation and Base-plates (Figs. 1 & 2).

FIG. I.



Elevation of base-plate, showing connexion with column above it.

FIG. 2.



Plan of base-plate.

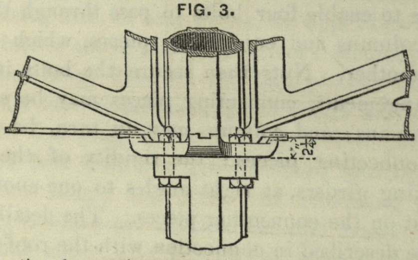
It would have been difficult to have found a better foundation than that which extends over the whole area of the building, with

the exception of a few "faults" here and there. Good gravel is reached at a depth of about 3 feet below the surface of the ground, and excavations have been made, in all cases, sufficiently deep to lay bare the gravel. The extent of the horizontal area of the excavation has been determined by a rule, that, making allowance for possible contingencies, the gravel cannot be exposed to a greater load that $2\frac{1}{2}$ tons per superficial foot. The cavities thus formed, have been, in all cases, filled up with solid concrete, finished with fine mortar. On the surface of this mortar are bedded "base-plates," or foundation pieces, consisting of a horizontal bed-plate, at right angles to the vertical lines of the building, strengthened by shoulders, uniting the horizontal plates to the portion of the base-plate, the section of which corresponds with that of the columns. The exact height, from the top of the concrete foundation to the plane of the junction between the base-plate and the column, has been so precisely calculated, and the casting of the base-plate has been, in all cases, so perfectly performed, that the snugs, cast on the upper portion of the base-plates, have exactly met and corresponded with those on the lower portion of the superincumbent columns, without leaving any interstice, or requiring any packing.

From the vertical portion of the foundation pieces, which carry columns, through which the roof-water passes, sockets branch out, into which are fixed the ends of the cast-iron pipes, for conveying the water descending from the roofs to the transverse drains.

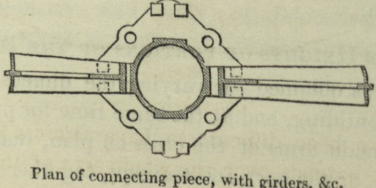
THE COLUMNS AND CONNECTING PIECES (Figs. 3, 4, & 5).

FIG. 3.



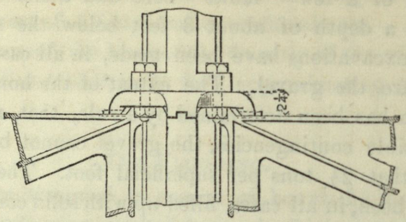
Elevation of lower portion of connecting piece, showing its attachment to a column below, and to the girders at the sides.

FIG. 4.



Plan of connecting piece, with girders, &c.

FIG. 5.



Elevation of upper portion of connecting piece, &c.

The form of the supporting columns bearing upon the upper face of the base-plates was suggested by Mr. Barry. The horizontal section is a ring, of which the external diameter is uniformly 8 inches, and the substance of metal is proportioned to the various areas of roofing, &c., to be supported at each point on the plan. The minimum thickness of the columns thus varies from $\frac{1}{2}$ inch to $1\frac{1}{8}$ inch; but the sectional area is increased by the addition of what would be equivalent to four fillets $3\frac{3}{8}$ inches by $\frac{5}{32}$ inch, cast upon the opposite portions of the ring, and facing, when fixed *in situ*, north, south, east, and west. Four snugs are cast on the top and four on the bottom of the columns, between these fillets. Corresponding snugs are cast on to connecting pieces; the snugs alternating upon the same plane, with the projections on the connecting piece which serve to carry the girders. Bolt-holes are cast in the snugs of the columns, and in those of the connecting pieces. All the bedding surfaces are accurately faced in a lathe, and are then fitted together, so as to enable four bolts to pass through the holes in the snugs of the columns and connecting pieces, which exactly correspond to one another. Nuts then secure the bolts in their places. By these arrangements, connecting pieces may be placed on, and attached to columns; and columns may, in turn, be placed on and attached to connecting pieces; the rigidity of the whole being secured, by fixing girders, at right angles to one another, on to the projections cast on the connecting pieces. The detail of these projections will be described in connection with the roof-trusses, which they serve mainly to keep in their places.

The largest number of columns fixed in one week was three hundred and ten.

Various Heights of portions of the Building.

Facilities are thus obtained for varying the dimensions in height of portions of the building, and at the same time for preserving lateral stiffness. The main arms of the cross on plan, that is, the avenues 72 feet in width, or the nave and transept, together with their aisles

24 feet wide, rise three stories in height; an avenue 48 feet wide, and an aisle 24 feet wide, on each side of the three-story building, rise two stories in height, and the whole of the remainder of the covered area is one story only in height. The gutter level of the three-story portion is 62 feet 2 inches from the floor; that of the two-story, 42 feet 2 inches; and that of the one-story, 22 feet 2 inches.

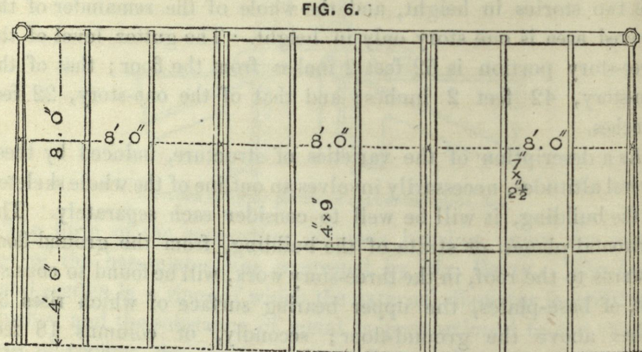
As a description of the varieties of structure, induced by these several altitudes, necessarily involves an outline of the whole skeleton of the building, it will be well to consider each separately. The horizontal planes, or strata of the building, from the ground-floor upwards to the roof, in the three-story work, will be found to consist, first, of base-plates, the upper bearing surface of which rises $3\frac{3}{4}$ inches above the ground-floor; secondly, of columns 18 feet $5\frac{1}{2}$ inches long, fixed on the base-plates; thirdly, of connecting pieces, 3 feet $4\frac{3}{4}$ inches deep, to which are attached cast-iron girders, 24 feet long, serving to support a gallery floor, at the height of 23 feet from the ground floor; fourthly, of columns 16 feet $7\frac{1}{4}$ inches long; fifthly, of connecting pieces 3 feet $4\frac{3}{4}$ inches deep, to which are attached transversely in one direction, and longitudinally in two directions, cast-iron girders 24 feet long, of similar form and scantling to the roof girders, in order to retain all the columns in their places; sixthly, of columns 16 feet $7\frac{1}{4}$ inches long; and lastly, of connecting pieces 3 feet $4\frac{3}{4}$ inches deep, to which are attached the roof trusses and girders.

The corresponding horizontal strata of the two-story portion of the building consist, first, of base-plates, the upper bearing surface of which rises $3\frac{3}{4}$ inches above the ground floor; secondly, of columns 18 feet $5\frac{1}{2}$ inches long, fixed on the base-plates; thirdly of connecting pieces, 3 feet $4\frac{3}{4}$ inches deep, to which are attached cast-iron girders, 24 feet long, serving to support a gallery floor, at the height of 23 feet from the ground-floor; fourthly, of columns 16 feet $7\frac{1}{4}$ inches long; and fifthly, of connecting pieces 3 feet $4\frac{3}{4}$ inches deep, to which are attached the roof trusses and girders.

The horizontal strata of the one-story portion consist, first, of base-plates, the upper bearing surface of which rises $3\frac{3}{4}$ inches above the ground-floor; secondly, of columns 18 feet $5\frac{1}{2}$ inches long, fixed on the base-plates; and lastly, of connecting pieces 3 feet $4\frac{3}{4}$ inches deep, to which are attached the roof trusses and girders.

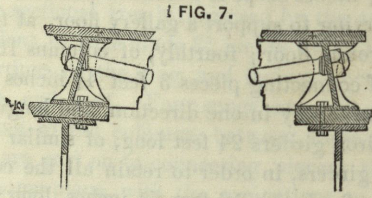
The Galleries (Figs. 6, 7, 8, & 9).

FIG. 6.



Plan of half of a 24-feet bay of the gallery floor.

FIG. 7.



Details of elevation of truss of gallery floor.

FIG. 8.

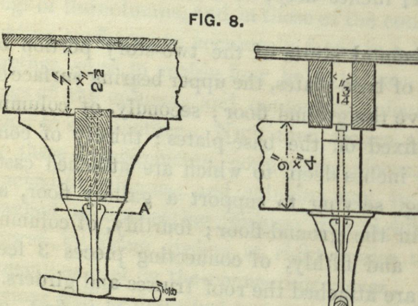
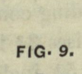


FIG. 9.



Plan of cast-iron standard to truss.

Sections of the truss.

From these dimensions it will be apparent, that at 23 feet above the floor level, galleries are inserted, which form striking features of both the two and the three story buildings. These galleries, in two widths of 24 feet each, with frequent connecting galleries, extend entirely round the upper portion of the building, and are supported by cast-iron girders 23 feet long, similar in form to those which support the roof, but of somewhat heavier scantling.

These single castings, 3 feet deep, are divided into three parallelograms of 3 feet by 8 feet, by vertical struts, connected at the top and the bottom by diagonal ties and struts. The sectional areas of their top and bottom flanges, in the centre of the length of the girder, equal respectively 5·31 inches, and 7·64 inches; those of the diagonal struts and ties average 3·50 inches. All these girders are proved, in the building, to a strain of 15 tons, and in exceptional cases, with extra scantlings, to 22 tons. Their breaking weight is calculated, and has been proved by experiment, to be not less than 30 tons. The binders, which serve to support the floor of these galleries, have been so arranged by under-trussing, by means of cast-iron shoes, rods, and struts, as to take their bearing upon four, instead of upon two girders; and thus any possible accumulated load, or vibration on a portion of the gallery, will be transferred to double the number of points of support that would have been available, had it been constructed in the ordinary manner. Joists of 7 feet 9 inches clear bearing, bridge these binders; and on them is laid a floor of boards 1¼ inch thick, with iron tongues, to prevent the passage of dust, &c. Ten double staircases, each 8 feet wide, enclosed by an iron railing, designed by Mr. Owen Jones, afford access to these galleries.*

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* Several experiments were subsequently tried, to ascertain the action of these galleries under the strain of a moving load. A complete bay, 24 feet square, was constructed, and raised slightly from the ground. Its area was covered with labourers packed as closely together as possible. No action of walking, running, or jumping of three hundred men did any injury to it. Soldiers, of the corps of Royal Sappers and Miners, were then substituted for the contractors' men, and although the perfect regularity of their step, in marking time sharply, appeared a remarkably severe test, no damage resulted from their evolutions.

Subsequently a very ingenious apparatus was devised by Mr. Field, the late President of the Institution of Civil Engineers, for the purpose of testing the stability of the galleries *in situ*, and on being applied over the greater part of the building, not a single bolt, or girder gave way under its action. The apparatus consisted of eight square frames divided into a number of compartments, each just capable of containing a 68-pound shot, and allowing it to rotate. The surfaces of the balls, placed in each of these compartments, came in contact with the gallery floor, the frames themselves being attached to one another, and running upon the floor by means of castors fixed at the angles. The whole apparatus being drawn along by a number of men, two hundred and eighty-eight 68-pound shot, confined in a limited area, were thus set rolling over more than half the whole extent of the galleries, when, not the slightest mishap having occurred, the experiment was considered decisive, and a persistance in it was deemed unnecessary.

THE FACEWORK (Figs. 10, 11, 12, & 13).

FIG. 10.

FIG. II.

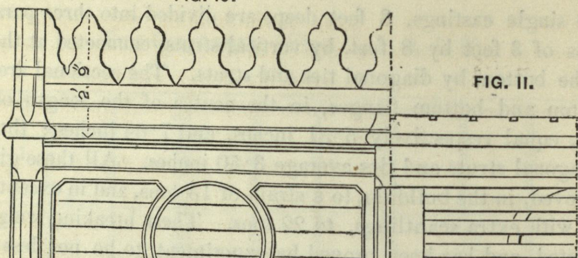
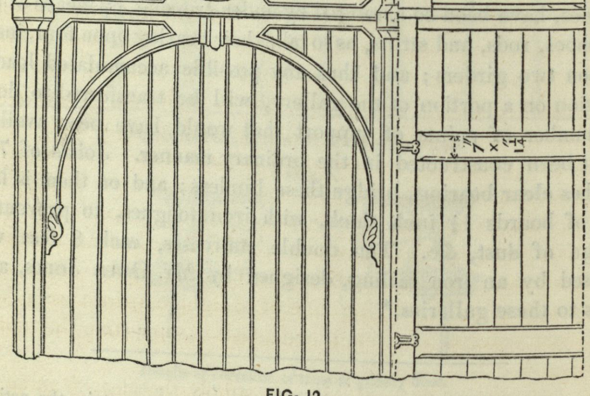


FIG. 12.
Section.



External elevation of an 8 feet bay of the facework of the lower tier.

Half internal elevation of the same.

Next to the internal supports of the building the external enclosures present themselves for consideration. It is obvious from the widths and heights given, that the north and south elevations, with the exception of the transept front, must consist of three stories, set back at various distances from each other.

These three stories are, the first, or ground floor; the second, or gallery floor; and the third, or clerestory floor.

On the ground floor, the cast-iron columns which carry the transverse roof-girders of the one-story building, constitute vertical divisions, at 24 feet from centre to centre; two wooden columns of precisely similar form, placed between the cast-iron ones, divide the 24 feet space into three bays of 8 feet each. The first horizontal line above the ground is a cill 9 inches by 3 inches, and 1½ inch above the floor level; beneath this cill, an enclosure of boards forms a plinth, against which rests a slope of turf, at an average level of 2 feet above that of the adjacent ground line. A second cill, 9 inches by 4 inches, is placed at a clear height of 4 feet 3½ inches from the lower one, the space between forming a kind of dado, and being filled in with louvres, which will be described under the head of ventilation. At 10 feet 6 inches from the upper surface of the second cill is the springing line of a light cast-iron arch, which spans from column to column, and assists in supporting the "filling-in frames."

These frames, sufficiently deep to supply the idea of an entablature, and yet so light and open as not to appear to overload the slender proportions of the columns, are 3 feet high, and are backed with louvres similar to those in the plinth. The parallelogram, bounded by the sides of the columns, the top of the dado, and the underside of the "filling-in frame," is filled in, on an inner plane, behind the arch pieces, with ploughed, tongued, and beaded boarding, stiffened by stout ledges on the inside. Small castings, spanning the inner face of the column, screwed to these ledges, connect them together; and are themselves fixed to the columns by bolts, passing completely through. On the top of the "filling-in frame" runs a boxing, with external mouldings, and behind the boxing is a small gutter. The whole is surmounted by a cast-iron ornamental cresting, 1 foot 6 inches high, attached to the boxing.

On the gallery-floor the upper parts of the columns supporting the two-story roof, constitute the main vertical lines. The space between is divided and filled up in a similar manner to that of the ground-floor, with two exceptions; first, that there is no dado, and secondly, that for the vertical boarding of the ground floor a

glazed sash is substituted. The frame of the sash is fixed to the columns by castings, similar to those which secure the ledges.

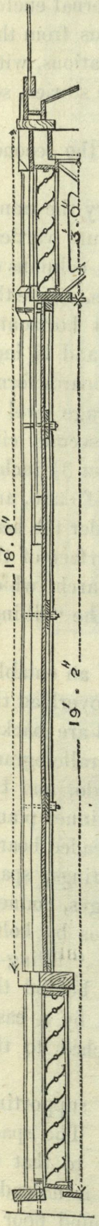


FIG. 13.

Vertical section of the facework of the lower tier.

The Sashes.

As these sashes form an important portion of the building, no fewer than 1,500 of them being required, a short description of them may be given. The sash-frames are $2\frac{1}{2}$ inches thick, with seven bars in their width; the sash-bars are $2\frac{3}{8}$ths inches deep, double-grooved for the glass; three bolts, $\frac{3}{8}$ths inch diameter, pass completely through the bars and frames, at the points where they are attached to the columns, and thus a chain tie is kept up all round the building, in order to prevent the displacement of the sashes, either bodily, or in portions, by the pressure of the wind. To further guard against the same action, timber bridges, $3\frac{1}{2}$ inches by $1\frac{1}{2}$ inch, in the centre, are fixed across the middle of the length of the sash; and at the internal angles, where the wind will exert its greatest force, iron rods, $\frac{1}{2}$-inch diameter, are fastened from column to column, pressing against the wooden bridge, and converting it into a continuous strut, bearing up against any force applied to the exterior of the sash. In order to glaze the sashes, the glass is slipped down between the bars, and provision is made for the repairs by causing one groove to be cut deeper than the other, so that the glass may be slipped in from either side, and puttied into its exact place. Similar provision is made for mending the roof-glass.

On the third, or clerestory floor, the external main vertical divisions are formed by the upper portion of the three-story columns, and the filling-in between them corresponds exactly with that of the gallery-floor.

The east and west elevations are simply vertical sections through the main building, filled in with facework similar to, and ranging with that of the three stories of the north and south elevations.

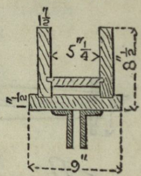
The elevations of the transept ends correspond with those of the east and west, with the exception of the addition of a semicircular head filled with concentric and radiating tracery.

The Exits.

In the circuit of the whole building there are fifteen exits, symmetrically disposed ; wherever they occur, a pair of doors, 8 feet in width, occupy the centre of the space, and the two bays of 8 feet each, on either side of the doors, are glazed instead of being boarded.

The Roof-Girders and Trusses (Figs. 14, 15, 16, 17, 18, 19, & 20).

FIG. 14.



Section of box-gutter on trusses.

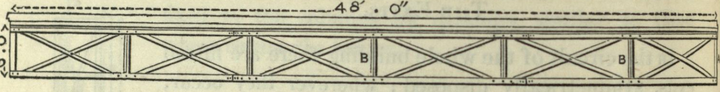
The net-work of girders and trusses immediately supporting the roof next demands attention. The main gutters, upon which the "Paxton gutters" are fixed, run transversely, spanning the various avenues leading from end to end of the building, except where it is crossed by the transept.

These avenues are all either 24 feet, 48 feet, or 72 feet wide ; of these avenues there are six 24 feet wide, five 48 feet wide, and one (the central) 72 feet wide. To span these widths at least three kinds of trusses are necessary. All the trusses, with the exception of four, are 3 feet deep, and have perpendicular struts of cast-iron, fixed at distances of 8 feet from centre to centre, connecting the top and bottom bars. The whole parallelogram, formed by the length and width of the trusses, is thus divided into smaller parallelograms of 8 feet by 3 feet, the four angles of which are diagonally connected by various materials, but of uniform width on the face, and thus regularity of form is obtained. The trusses of 72 feet and 48 feet span consist of cast-iron standards and vertical struts, an upper portion formed of two pieces of angle iron, set 1 inch apart, a bottom portion of two bars, increasing in sectional area as they approach the centre of the bearing, and tie-bars, which, passing diagonally between the two pieces of angle iron in the upper portion and the two bars in the lower, are rivetted to them, and form a complete suspension truss. The remaining diagonals in the opposite direction, which would, if in action, be under compression, are con-

FIG. 15.

Elevation of ordinary 72 feet truss.

FIG. 16.



Elevation of ordinary 48 feet truss.

FIG. 17.

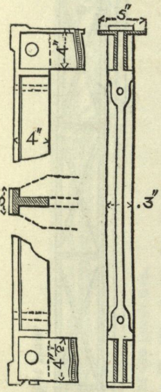
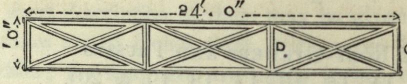


FIG. 19.



Elevation of 24 feet cast-iron girder.

FIG. 20.

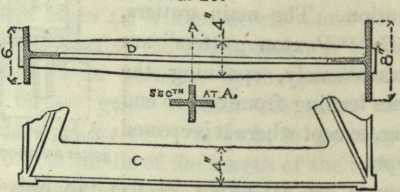
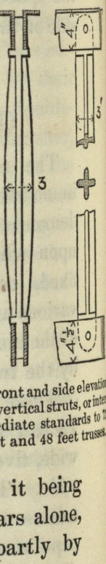


FIG. 18.



Front and side elevations of end standards to 72 feet and 48 feet trusses.

Front and side elevations of ends of cast-iron girder.

Front and side elevations of vertical struts, or intermediate standards to 72 feet and 48 feet trusses.

structed of wood, and are only inserted for appearance, it being thought better to resist the diagonal strains by tension bars alone, rather than partly by diagonal suspension bars, and partly by diagonal struts.

The girders of 24 feet long are single castings, corresponding in form to those which support the galleries, the arrangement and scantlings of the various parts of which have been elaborately studied and balanced. Every one of these trusses has been proved, in the building, with a strain of nine tons. The largest number of girders cast in any one week was three hundred and sixteen.

The Experiments tried on the Roof-trusses and Girders.

Previous to deciding upon the scantling of the trusses to be used in the building, Mr. Charles Heard Wild and the Contractors entered into an elaborate series of calculations, as to the adjustment and proportions of the various parts. These calculations were submitted to the President of the Institution of Civil Engineers, and their correctness was so completely justified, by the results of some experiments on the trusses and girders, made in his presence and in that of the Author, that a summary must be interesting.

A 72-feet truss, cambered $4\frac{1}{8}$ inches, and weighing complete about 35 cwt.,

The maximum sectional area of the two top angle-irons being	5·71	inches.
The maximum sectional area of the two bottom bars being	6·75	,,
The maximum sectional area of the principal diagonal tie being	3·38	,,

when loaded with a weight of—

4 tons,	deflected	$1\frac{1}{4}$ inches.
6	,,	$2\frac{1}{2}$,,
8	,,	$3\frac{3}{8}$,,
10	,,	$4\frac{1}{8}$,,
12	,,	5 ,,
14	,,	$5\frac{5}{8}$,,
16	,,	$6\frac{1}{2}$,,

A 48-feet truss, cambered 4 inches, and weighing complete about 13 cwt.,

The maximum sectional area of the two top angle-irons being	3·0	inches.
The maximum sectional area of the bottom bars being	3·38	,,
The maximum sectional area of the principal diagonal tie being	2·75	,,

when loaded with a weight of—

tons	cwt.		
2 tons	10 cwt.	deflected	$\frac{1}{2}$ inch.
5	0	,,	$1\frac{1}{2}$,,
7	10	,,	$2\frac{1}{8}$ inches.
8	15	,,	$2\frac{3}{8}$,,
10	0	,,	3 ,,

A 24-feet girder, weighing complete 11 cwt. 3 qrs., exactly similar in construction to the 24-feet roof-girders, but 2 cwt. 1 qr. heavier, bore 30 tons, but broke down with $30\frac{1}{2}$ tons, flying so completely to pieces that doubts existed as to the point at which fracture commenced.

The Extra-strong Trusses (Figs. 21, 22, 23, 24, 25, 26, 27, & 28).

The four 72-feet trusses which have been alluded to, as differing from the others in depth, perform such important functions, and are consequently so different in form, as to warrant a separate notice. They support the lead flat, covering two bays (each 24 feet by 72 feet) of the main avenue, where it abuts upon the eastern and western sides of the transept, and a pair of them carry, in addition, the two semi-circular ribs, which, at 24 feet from centre to centre, form the main beams on which the semi-cylindrical roofing rests, over the square where the transept roof crosses the main longitudinal avenue.

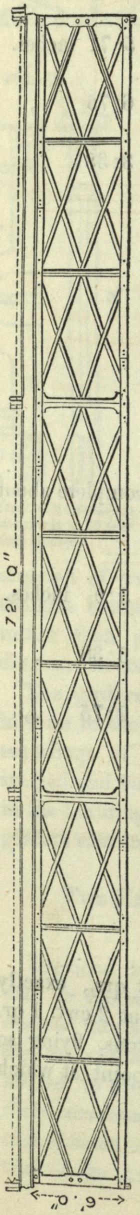


FIG. 21.
Elevation of extra strong 72 feet truss.

These trusses are made twice the depth of all the others, and the scantlings are considerably increased. In this extra depth the vertical struts remaining at 8 feet from centre to centre, and the tension bars continuing the same in number, and being set at the same angle as those in the ordinary trusses of 72 feet span, the lines arrange themselves into a lattice-form two diamonds in depth, the intersecting diagonal bars passing through slots cast for them in the middle of the cast-iron struts. Although the form would appear to be that of a compound truss, the strength of all the parts is calculated so as to render these trusses suspension trusses only. In order to relieve the ordinary columns of much of the weight which is supported by these trusses, additional columns are placed beneath their two ends, secured, at frequent intervals, to the ordinary columns by wrought-iron clips.

The Semicircular Ribs (Figs. 29, 30, & 31).

In order to form an idea of the nature of the work the extra-strong trusses have to perform, the structure of the semi-circular ribs must be defined. They are made in three thicknesses of timber, each 9 feet 6 inches long, cut into segments of a circle 74 feet extreme diameter, the central thickness being 4 inches by 13½ inches,

FIG. 22.

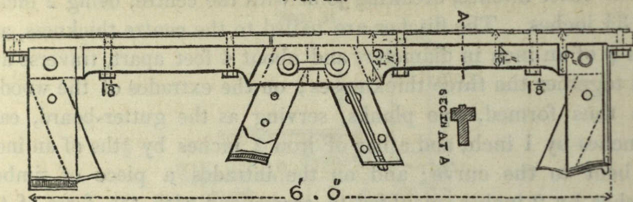


FIG. 23.

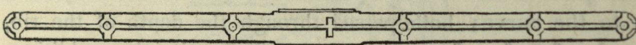
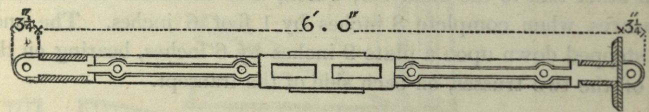


FIG. 24.



Side, front, and back elevations of the end standard to extra strong 72 feet truss.

FIG. 25.

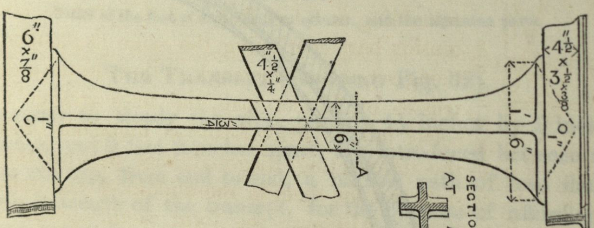
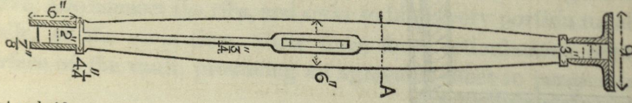


FIG. 26.



Front and side elevations, with plan of the cast-iron vertical struts, or intermediate standards, to extra strong 72 feet truss.

FIG. 27.

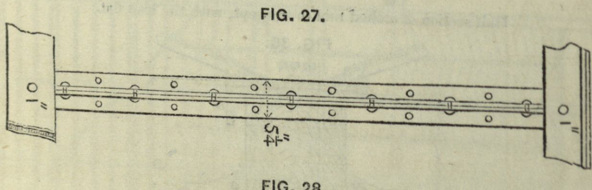
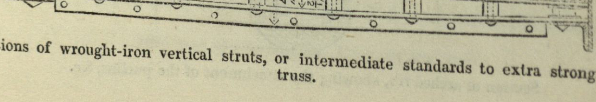


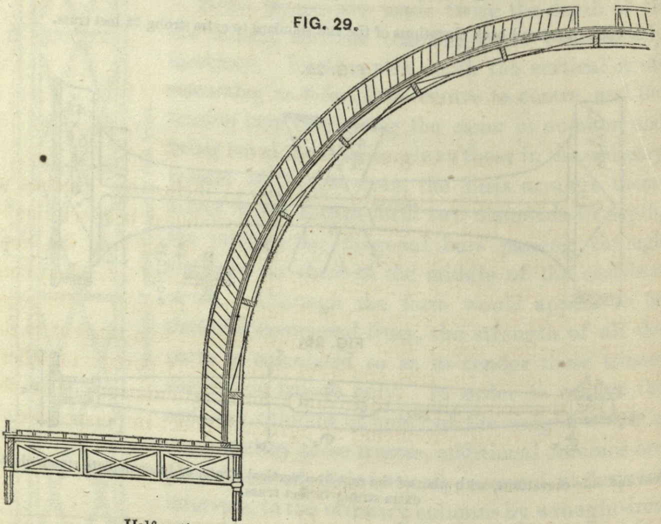
FIG. 28.



Elevations of wrought-iron vertical struts, or intermediate standards to extra strong 72 feet truss.

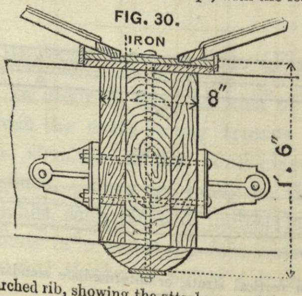
and the outer flitches, breaking joint with the centre, being 2 inches by $13\frac{1}{2}$ inches. The flitches are nailed to the centre thickness, and bolts $\frac{5}{8}$ of an inch in diameter, and about 4 feet apart, traverse and bind together the three thicknesses; on the extrados of the wooden arch thus formed, two planks, serving as the gutter-board, each 11 inches by 1 inch, and a bar of iron 2 inches by $\frac{3}{8}$ths of an inch, are bent to the curve; and on the intrados a piece of timber, 7 inches by 2 inches, moulded to correspond with the form of the columns, and a bar of iron $3\frac{1}{4}$ inches by $\frac{3}{8}$ths of an inch, are also bent to the curve; bolts passed through the depth of the rib, at intervals of 2 feet from centre to centre, unite these additions to each other and to the main rib, which, thus increased in scantling, measures when complete 8 inches by 1 foot 6 inches. The ends are stepped down upon a plate 9 inches by 6 inches, bearing on the top of the two trusses, on each side of the transept.

FIG. 29.



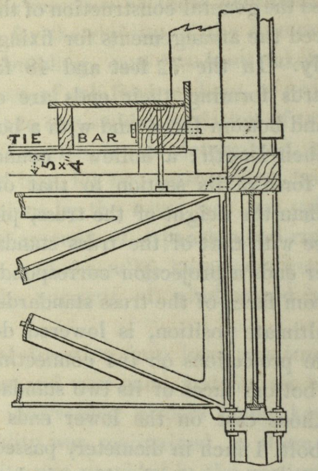
Half section of arched roof to transept, with the lead flat.

FIG. 30.



Section of arched rib, showing the attachment of the purlins, &c.

FIG. 31.

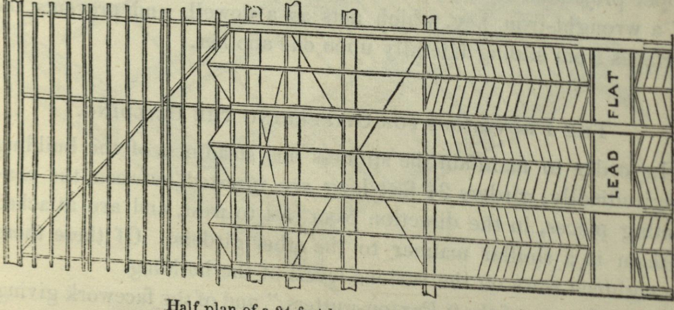


Detail of the foot of arched rib on column, and the adjoining parts.

The Transept (Roofing Fig. 32).

In order to steady the ribs, purlins $4\frac{1}{2}$ inches by 9 inches to 13 inches, and 9 feet 2 inches apart, are introduced between them; and on the top, from end to end, a narrow path of lead flat runs the whole length of the transept, for the purpose of affording convenient access for any repairs which may be necessary. Diagonal rods, intersecting each other in planes parallel to a tangent to the curve, also connect the ribs, and serve to bind every portion together; while, at the same time, their lines form reticulations over the surface of the vault, producing an agreeable effect in perspective.

FIG. 32.



Half plan of a 24 feet bay of the transept roof.

The Connexions of the Roof Trusses, &c.

Having indicated the general construction of the roof trusses, there remain to be noticed the arrangements for fixing and for steadying them longitudinally. In the 72 feet and 48 feet trusses, respectively, the standards forming their ends are cast with a projection on their top and bottom faces, and with a bolt-hole through the upper portion of their length; a hollow "connecting piece," corresponding in the form of its section to that of the columns, and 4¾ inches longer than the height of the truss, pierced through with a bolt-hole to agree with that of the truss standard, has cast upon its upper and lower ends a projection corresponding with those cast on the top and bottom faces of the truss standards. The truss being hoisted above its ultimate position, is lowered down until it can be slipped between the projections on the connecting piece, when the projections on the bottom faces of its two standards take a bearing, and clutch on to those cast on the lower ends of the connecting pieces. A screw bolt, 1 inch in diameter, passed through the bolt-hole of the standard, and completely through the connecting piece, secures the upper part of the truss from lateral motion, and together with the stiffening of the "Paxton-gutters," counteracts any tendency to buckle. The means provided for fixing the cast-iron roof girders of 24-feet span, into the connecting pieces, are precisely similar to those above described, but the mode of securing them from lateral movement is somewhat different. Instead of the bolt-fastening of the trusses of 72 feet and 48 feet spans, a groove is sunk in the middle of the top and bottom projections of the connecting piece, and a corresponding tenon is cast on the bottom of the standard of the 24 feet girder. The bottom of the truss is thus held in its place, by the fitting of its tenon into the lower groove of the connecting piece, while the upper projection of the truss, having a groove cut in it, to correspond with that on the under side of the upper projection of the connecting piece, is secured by the insertion of a wrought-iron key, which acts as a dowell, and prevents the surfaces from sliding laterally upon one another.

The Provisions for Stiffening the Building.

In order to maintain the stiffness and steadiness of the building longitudinally, girders 24 feet long are inserted between the connecting pieces, in the direction from east to west, and are attached to them in a similar manner to the other girders. Of these there are eighteen rows on the various levels of the building.

The influence of the "Paxton-gutters," and of the facework giving

additional stiffening to the whole, adds considerably to the good results obtained by the insertion of these longitudinal girders.

In thus providing for the rigidity of the connexions of the various portions of the building, care has been taken, by the substitution, in certain places, of oak for iron keys, to provide for the play of the metal, incident to any sudden variation of temperature.

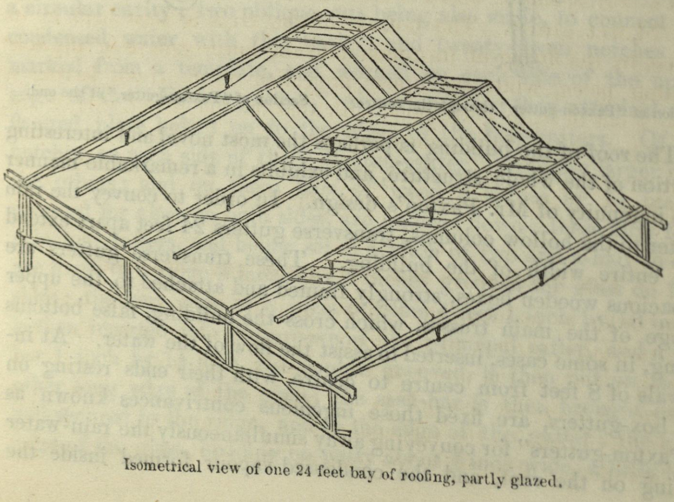
In the transverse direction, it was determined, that the whole of the keys should be of iron, for two reasons, first, because the length, divided into two portions by the nave, was not sufficiently great to render the probable amount of expansion, or contraction, of any practical importance, and secondly, because it was upon the side of the building that the currents of wind would impinge with the greatest force.

In the longitudinal direction, iron keys are inserted for six bays from the extreme east and west ends, and for six bays east and west of the transept, the intervening girders being keyed up with oak keys: and thus rigidity was maintained in those parts exposed to strain, whilst elasticity was provided in the portions of the building least subject to strain from without.

Twenty-two sets of horizontal, and two hundred and twenty sets of vertical diagonal bracing, consisting of wrought-iron rods secured by wrought-iron links to the columns and connecting pieces, and meeting in adjustment plates, are inserted as a measure of extra precaution, tying the main masses of the structure together.

THE "PAXTON" ROOFING (Figs. 33, 34, 35, 36, 37, 38, & 39).

FIG. 33.



Isometrical view of one 24 feet bay of roofing, partly glazed.

FIG. 34.

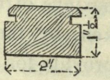
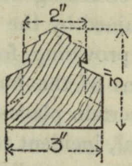


FIG. 35.

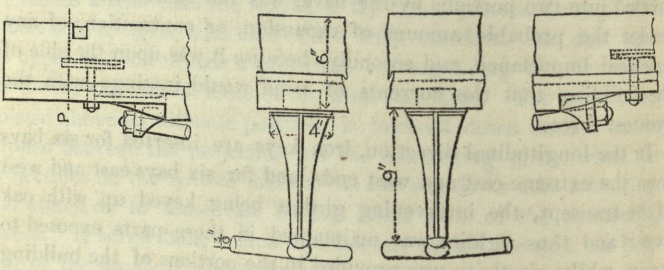
Sections of extra strong and ordinary sash-bars.

FIG. 36.



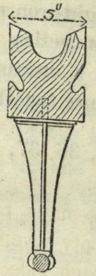
Section of the ridge.

FIG. 37.



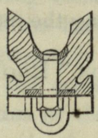
Elevation of portions of a "Paxton-gutter."

FIG. 38.



Section of "Paxton-gutter" through the centre.

FIG. 39.



Section of "Paxton-gutter" at the end.

The roof of the building is perhaps the most novel and interesting portion of the whole structure, and exhibits in a remarkable manner the ingenuity of Mr. Paxton's design. In order to convey the rain water to the hollow columns, transverse gutters 24 feet apart extend the entire width of the building. These transverse gutters are capacious wooden boxes, strongly framed and attached to the upper flange of the main trusses, which cross the building, false bottoms being, in some cases, inserted to assist the flow of the water. At intervals of 8 feet from centre to centre, with their ends resting on the box-gutters, are fixed those ingenious contrivances known as "Paxton-gutters" for conveying away simultaneously the rain-water falling on the roof, and the condensed vapour formed inside the

building, and of them a length of 24 miles is required. Each one of these consists of a piece of the best crown timber, 5 inches by 6 inches and 24 feet long. The form is given by passing it through an ingenious machine, worked by Mr. Birch of the Phœnix Saw Mills, Camden Town. At one operation, this machine scoops from the middle of the upper surface of the timber, and throughout its whole length, a nearly semicircular groove about $1\frac{3}{8}$ inch radius, and at the same time cuts two smaller grooves downwards at an oblique angle to its sides; the object of the larger groove being to receive and convey to the box-gutters the roof-water, and that of the smaller grooves to receive the moisture, which, condensing upon the inside of the roof, would trickle down, adhering by capillary attraction, and finally deposit itself in the smaller grooves, by which it would be conducted to the box-gutters. On leaving the machine, the "Paxton-gutter" is too slight for a bearing of 24 feet, and is straight, so that the water in it would not have any fall; both these defects are remedied by trussing it into a curve, by means of a wrought-iron bolt, $\frac{13}{16}$ inch diameter, threaded at both ends, and bent so as to pass under and press up, to the underside of the wood, two cast-iron struts 9 inches long; the ends of the bolt being passed through holes in the two cast-iron shoes, fixed at the ends of the gutters, and the nuts on the ends of the bolts being screwed up, the bolt is tightened, and a camber of $2\frac{1}{2}$ inches is given to the gutter, so that the whole becomes a truss, requiring a weight of $1\frac{1}{2}$ tons to break it. A semicircular cut is then given through the depth of the gutter at both ends, so that when two are placed end to end, the water will flow down into the box-gutter through a circular cavity; two oblique cuts being also made, to connect the condensed water with this cavity, and twenty-seven notches are marked from a template, and worked on each side of the upper edge of the "Paxton-gutters," whose ends are then attached to a flanged plate bolted on to the edges of the box-gutters. Of the notches on each side of the "Paxton-gutter," three are larger than the others; and on them bars of wood 2 inches by $1\frac{1}{2}$ inches, grooved for glass on both sides, are notched down; these bars form principal rafters, and being set at a pitch of two and a-half to one, are fixed to a ridge 3 inches by 3 inches grooved for glass on both sides; the long edge of a sheet of glass 4 feet 1 inch by 10 inches is then inserted into the groove of the principal rafter, and a sash bar 1 inch by $1\frac{1}{2}$ inch, also double grooved, is then put on to the other long edge of the glass; the sash-bar is then brought down, and secured to the ridge, and to the edge of the gutter; the lower edge of the glass, bedding on putty about $\frac{3}{4}$ inch wide, a little force

applied at the lower end brings the upper edge of the glass home into the groove in the ridge. The glass being then pressed down, the putty is made good in the grooves externally, and thus simply is this system of roofing put together. Its lightness is one of its remarkable qualities, since the entire weight of one superficial foot averages only $3\frac{1}{4}$ lbs.

The largest quantity of "Paxton-gutters," each 24 feet in length, planed and grooved by one machine in one week, was four hundred and forty-two.

The "Paxton" Roofing over the Transept.

The area of 29,376 feet, forming the transept, is covered with roofing, similar in many particulars to that adopted by Mr. Paxton in the great conservatory at Chatsworth. The width which is spanned by the semicircular ribs, at intervals of 24 feet from centre to centre, is 72 feet. Purlins 9 feet 2 inches apart, connect the semicircular ribs, and between them, at distances of 8 feet from centre to centre, are framed smaller ribs, the backs of which, as well as those of the main ribs, form water-courses, and convey the rain on to the lead flat running 24 feet in width, on each side, at the base of the semicircular ribs of the roof. These latter, which stand at 8 feet apart, are then connected by ridge and furrow roofing, the construction of which is nearly identical with that previously described as employed in the smaller roofs. Beneath the lead flat is constructed a horizontal truss consisting of bars, calculated to transfer the strain to the points most securely tied and abutted, and thus to counteract any tendency of the ribs to spread, or to shift under the action of wind.

In connexion with the design for the building, there are still three important items to be considered:—the ventilation,—the mode to be adopted of tempering the intensity of the sun's rays,—and the supply of water immediately available for the extinction of fire.

The Ventilation (Figs. 40 & 41).

Is obtained by means of louvres set in boxings, inserted behind the "filling in" frames of each of the three stories of the building—and in the dado, between the lower and upper cills on the ground floor. At the springing of the transept roof, a line of louvres is inserted on both sides, 3 feet 8 inches high, running the whole length of the transept; and at the very summit of the curved roof, ventilation is obtained in the gables of the roofing, where it is interrupted by the narrow path of upper lead flat. The total quantity of venti-

lating area in the louvres equals about 45,000 feet, in addition to which, large volumes of air will necessarily be introduced at the numerous doorways. The louvre frames on the ground floor consist of boxes, in which eight louvre blades of galvanized iron $6\frac{1}{2}$ inches wide, are fixed on pivots at 6 inches from centre to centre, and so curved as to offer the minimum interruption to the ingress, or egress of air when open, compatible with keeping them weather tight.

FIG. 40.

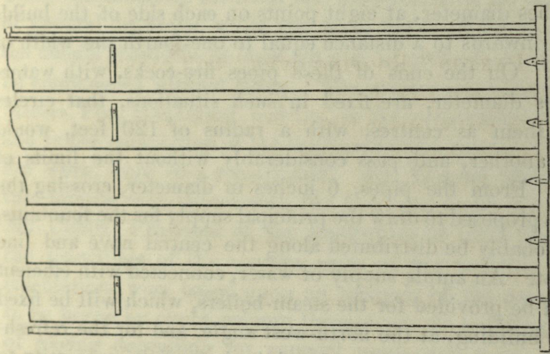
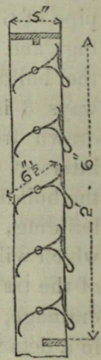


FIG. 41.



Part elevation and section of one of the louvre frames.

Small iron brackets, attached to the centre of each blade, are furnished with eyes, through which are inserted pins, passing also through holes bored at equal distances from one another, in a species of rack; by drawing these racks up and down, the opening and closing of the ventilators is effected. A number of these racks will, of course, be attached to levers, and set in motion by rods and cranks; Mr. Fox has designed an ingenious method of producing the simultaneous action of a considerable number, and at the same time of securing the uniform position of the louvre blades at any desired angle.

Should it ever be found necessary to reduce, by artificial means, the internal temperature of the building below that of the exterior, Mr. Paxton has proposed a system of cooling, applicable to these ventilators, somewhat on the principle of the Indian "tatties."

The Canvas Covering.

In order to diminish the intensity of the light and heat of the sun's rays, it is proposed to cover the whole of the roof and of the south side of the building with canvas, which will be attached to the sashes on the side, and span from ridge to ridge on the roof, the seam being arranged to occur directly over the gutters.

The Water Supply.

The water is supplied by the Chelsea Water-works Company, through a main pipe 9 inches in diameter, branching into three pipes 6 inches in diameter, at the centre of the building, on the south side, at about 35 feet from the entrance.

These latter pipes go entirely round the building, and across the centre; twenty cocks of 3 inches diameter are attached to these pipes externally; eight pipes, 4 inches diameter, branch from the pipe of 6 inches diameter, at eight points on each side of the building, and run inwards to a distance equal to one-fourth the width of the building. On the ends of these pipes fire-cocks, with water-ways 3 inches diameter, are fixed in such situations, that circles drawn from them as centres, with a radius of 120 feet, would intersect one another, and pass considerably without the limits of the building. From the pipes, 6 inches in diameter, crossing the building, it is proposed to draw the principal supply for the fountains, which will probably be distributed along the central nave and line of the transept. An ample supply of water, connected with efficient drainage, will be provided for the steam-boilers, which will be fixed in a detached building, at the north-west angle, and for the refreshment-rooms, &c., which will be placed in immediate proximity to the trees beneath the transept.

It can scarcely be expected, that the limits of the present paper should comprise all that is worthy of remark in a building, the vast size of which involves considerable complexity of parts; it is hoped, therefore, that indulgence will be exercised, if, in this hasty description of the design of the building, much that is worthy of comment should have been lightly passed over, or altogether omitted.

The Execution of the Works.

In proceeding to the third part of the subject, the power and dexterity with which the design has been realized, or, in other words, the actual construction of the building, the feature that first claims attention is the celerity with which the various operations have proceeded. When it is remembered that Messrs. Fox, Henderson, & Co.'s tender was only verbally accepted on the 26th of July, 1850, that possession of the site was only given on the 30th of the same month, that the first column was fixed on September 26th, exactly two months after the acceptance of the tender, and that at the present moment but little of this vast building remains to be finished, it must be felt, that England possesses mechanical appliances and physical energies, far exceeding those which gave form and being to the most celebrated monuments of antiquity.

The total number of men employed in each week varied from thirty, in the week ending August the 3rd, to two thousand two hundred and sixty in the week ending December the 6th.

Modifications of the Original Design.

Previous to the acceptance of the tender, various modifications of the design were made, and from Mr. Barry's refined perception of form and proportion, valuable structural improvements were derived. These modifications involved the preparation of an entirely new set of general drawings, while the rapid flight of time demanded that the details should be at once got out, in order that the work might be commenced without delay. The energy and ability displayed by Messrs. Fox, Henderson, and Co., in the preparation of these details, and in the completion of the necessary arrangements for carrying on the work, were very remarkable. Mr. Charles Heard Wild went into minute calculations with Mr. Fox, and under the supervision of Mr. Cubitt, President of the Institution of Civil Engineers, fixed the scantlings of the various parts of the building. Mr. Wild's calculations were based upon an analysis of the amount of weight to be borne by every column throughout the building, and the area of roofing depending for support upon each truss, making liberal allowances for the additional weight of snow. At an early stage in the proceedings, the Author, with Mr. Wild, and Mr. Owen Jones, had been selected by the Building Committee to assist them in their labours, and to superintend the erection of the building. Under the supervision of Mr. Cubitt, the Chairman of that Committee, they have been constantly employed up to the present time. Mr. Owen Jones went carefully over every form in the building susceptible of harmonious combination, and has zealously occupied himself with every detail of arrangement likely to benefit by the exercise of his taste and knowledge. While the general drawings were quite incomplete, various details were so far settled, that the patterns for much of the ironwork could be made, and the trusses and girders be experimented upon. The celerity with which the girders, columns, &c., have been executed and forwarded is remarkable. In one week as many as three hundred and eight girders were delivered at the building.

The Proving of the Girders (Figs. 42, 43, & 44).

To prove the girders, a very ingenious apparatus, connected with an hydraulic press and register, was contrived by Mr. Wild, by means of which the girders are perfectly gauged, and in which they are retained in an inverted position. Pressure is then applied up-

wards from two pistons, at the points in the upper table of the girders upon which, in the roof-girders, the "Paxton-gutters" will

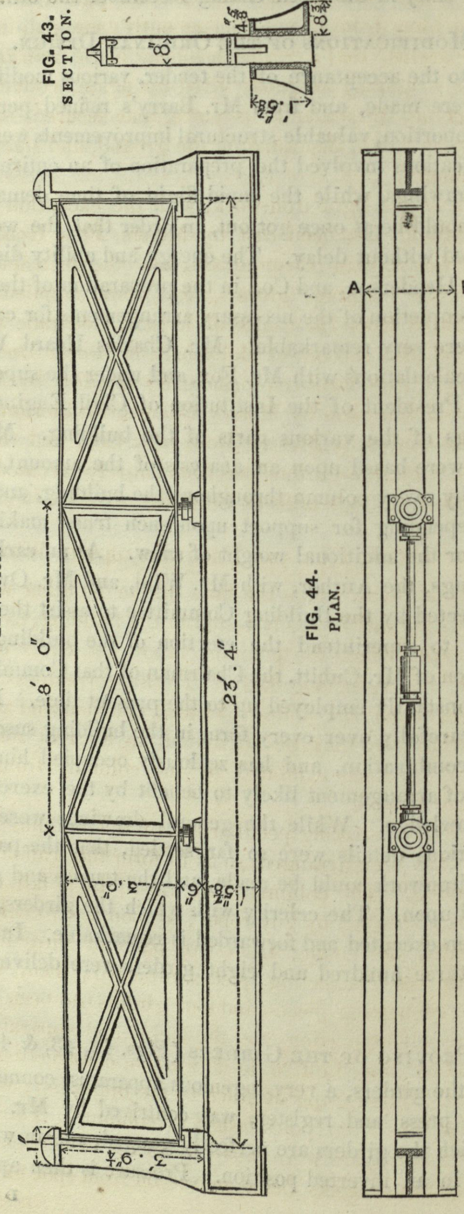


FIG. 43. SECTION.

FIG. 42. ELEVATION.

FIG. 44. PLAN.

Plan, elevation, and section of the frame in which the cast-iron girders were fixed for proving by the hydraulic press.

bear, and in the gallery-girders, the binders, and thus the proof is applied in a similar manner to that in which the girders will be eventually loaded. One of Mr. Henderson's patent cranes, and a weighing-machine, have been so conveniently arranged, in connexion with this apparatus, that a girder has been lifted from the waggon, deposited for weighing, weighed, lifted up again, conveyed to the proving machine, slipped into its place, and secured,—proved, released, taken up again, deposited on the ground, and stacked, in less than four minutes.

The whole of the light iron-work, with the exception of some of the gallery railing, has been cast by Messrs. Fox, Henderson, and Co., at their works, near Birmingham, and the principal castings, consisting of the columns, girders, &c., were supplied all ready turned and fitted from the works of Messrs. Cochrane and Co., of Woodside, and Mr. Jobson, of Holly-hall, both near Dudley.

The wrought iron has been principally supplied by Messrs. Fothergill & Co.; the glass by Messrs. Chance, Brotherton, & Co., of Oldbury; the timber by Messrs. Dowson & Co.; and the machine cutting of the "Paxton-gutters" has been entirely executed at Messrs. Fox, Henderson, & Co.'s mills at Chelsea.

The Setting Out and Progress of the Work.

The perfection with which the lines of the building were set out by Mr. Browngar will be easily tested in the building, by remarking the precision with which the columns range and cover one another diagonally as well as rectangularly. To this correctness, and to the careful setting of the base-plates (of which one thousand and seventy-four were required), may be attributed, in a great measure, the uniformity of the lines exhibited by the columns from whatever points they are viewed.

One of the most striking peculiarities of this building is the skill with which it has been arranged, so as to form the scaffolding for its own construction. The columns were raised by a fall descending from shear-legs, steadied by guy-ropes; so soon as two columns were fixed, two falls, descending from two pairs of shear-legs, raised a girder with the connecting pieces attached; then, when four columns, four connecting pieces, and four girders had been raised, the whole became self-supporting, and the tackle and apparatus, used to erect it, could be moved off to do its work in constructing a similar bay elsewhere. The raising of much of the upper tiers was effected by suspending falls from poles lashed to columns. The trusses of 48 feet and 72 feet spans were raised by means of derricks, steadied by guy-ropes, the derricks being moved on from spot to spot in a

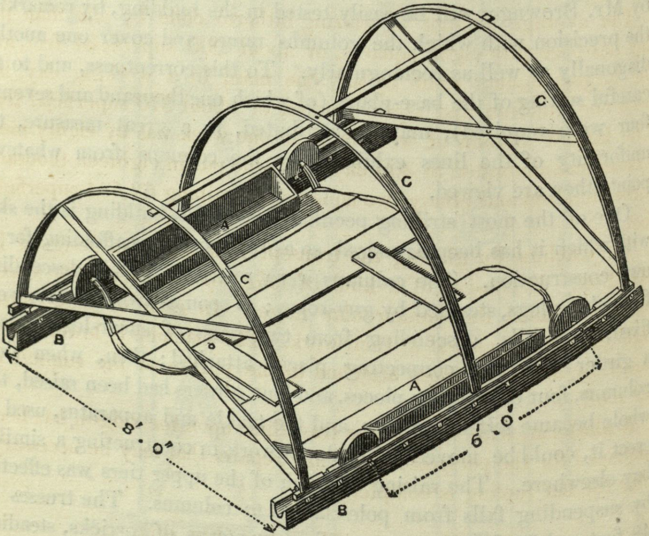
perpendicular position. The way in which the men managed to retain the derricks in a perpendicular position, by alternately tightening, slackening, and shifting the guys, was really admirable. By this means as many as seven of the great trusses of the nave have been raised in one day; the derricks (for one was at work at each end of the building) thus travelling 168 feet.

The active superintendence and direction of the whole of the labour devolved upon Mr. John Cochrane, Mr. Earee acted as clerk of the works to the Commissioners, and Mr. Harwood as their surveyor.

During many weeks upwards of two thousand men were constantly employed upon the ground; four steam-engines assisting in the various operations, and affording motive power to a variety of machinery for facilitating production. Ingenious arrangements of circular saws, and revolving gouges, &c., cut and bored different portions of sash-bars, ridges, and "Paxton-gutters." Huge shears, and punching and drilling machines combined to prepare the truss-bars for being rivetted, and portable forges supplied the means of heating the rivets for the three hundred and seventy-two wrought-iron trusses, of which as many as sixteen have been rivetted up in one day.

The Glazing Machines.

FIG. 45.



Travelling stage for glazing the roofs.

A. Box for glass. B. Trussed girder. C. Frame to support the covering used in wet weather.

It was of great importance that arrangements should be made for carrying on the glazing of the roofs independently of weather. To effect this purpose a travelling stage was devised by Mr. Fox, which superseded the necessity of any scaffolding for glazing, and by means of seventy-six of these machines nearly the whole of the work has been executed. The stage is about 8 feet square, and it rests on four small wheels, which travel in the "Paxton-gutters." It thus embraces one bay of a span of 8 feet of the roof, with one ridge and two sloping sides; each bay in width requiring a separate stage. The stage, occupied by two workmen, is covered by an awning of canvass, stretched over hoops to protect them in bad weather, and is provided with two boxes, to contain a store of glass. The sash-bars and other materials are piled upon the stage itself, the centre of the platform being left open, for the convenience of hoisting up materials.

Whilst working, the men sit at one end of the platform (the ridge having been previously placed in position by means of the extra-strong sash-bars), and fix the glass in front of them, pushing the stage backwards as they complete each pane. On coming to the strong sash-bars previously fixed, they temporarily remove them, to allow the stage to pass: in this manner each stage travels uninterruptedly from the transept to the east and west ends of the building.

The average amount of glazing hitherto done by one man per day has been fifty-eight squares, or about 200 superficial feet, and the largest amount done by any one man, in a working day, has been one hundred and eight squares, or about 370 superficial feet. The largest amount of work done in one week was by eighty men, whose time amounted to 309 days, and who put in eighteen thousand three hundred and ninety-two squares, containing 62,584 superficial feet.

The machine for glazing the transept roof was also designed by Mr. Fox. It consists of a kind of long wooden box, with wheels running against the semicircular ridge. In each of these boxes eight glaziers can stand at their work. The machine is lowered and raised by means of ropes attached to the purlins at the summit of the roof.

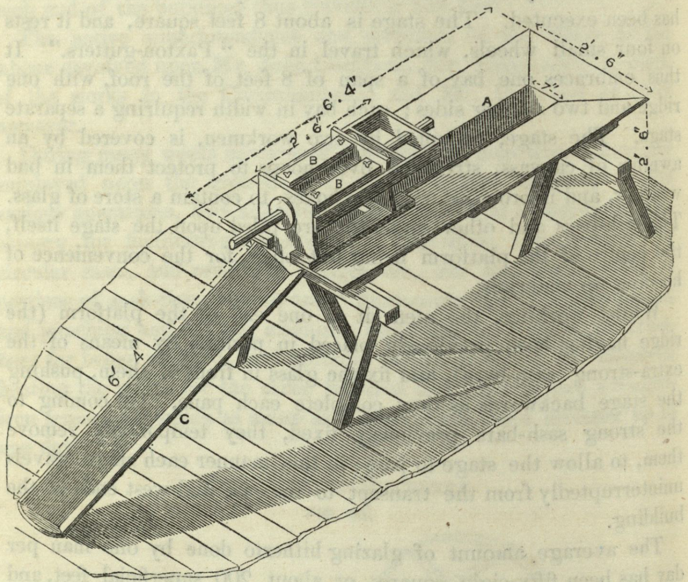
A platform, with wheels also travelling upon the ridges, has been contrived for the performance of any repairs that may be necessary, after the flat roofing is completed.

The Painting Machine (Fig. 46).

An ingenious machine has been adopted for painting the sash-bars. A trough being filled with liquid colour, the sash-bars are

dipped into it, and when taken out, are passed through a series of brushes set at such angles to each other as to entirely remove the superfluous paint, and to leave the sash-bar as neatly finished as it could have been by hand.

FIG. 46.



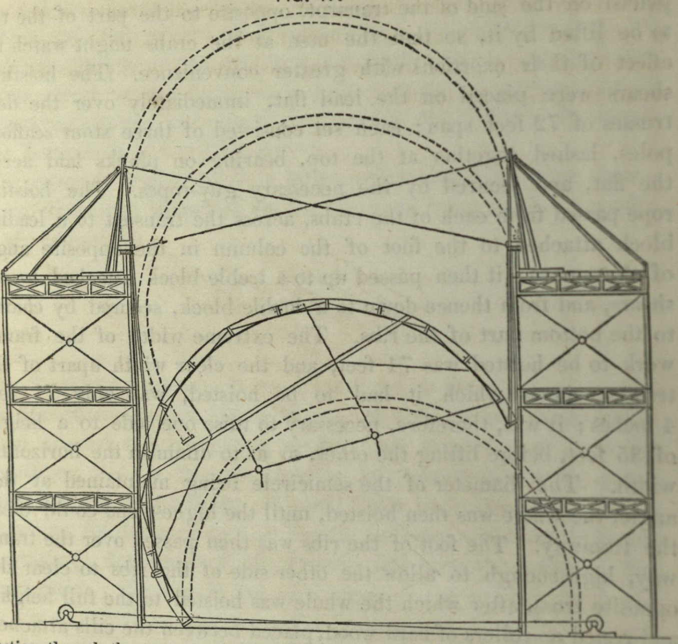
Machine for painting the sash-bars.

A. Trough for holding paint. B. The brushes. C. Spout for waste paint.

Mode of Raising the Transept Ribs (Figs. 47, 48, & 49).

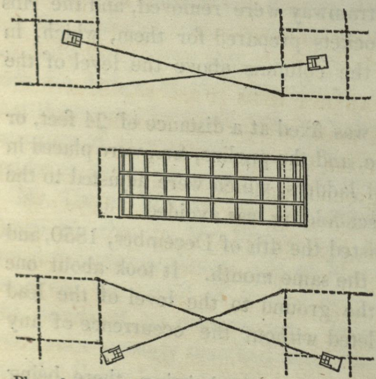
The operation about which most anxiety had been felt was the hoisting of the arched ribs of the transept. These ribs were constructed horizontally on the ground, and when completed with all their bolts, two of them were reared on end, and maintained in a vertical position, at a distance of 24 feet from each other, by guy-ropes. As the ribs possessed little lateral stiffness, they were framed together with the purlins, intermediate small ribs, and diagonal tie-rods, forming a complete bay of the roof, 24 feet long. Two complete sets of temporary ties were also introduced, to provide for the strains incident to the variations in position of the ribs, during the hoisting: the feet of the ribs were bolted on to a stout cill, and the lower purlins were strutted up from it. The whole framework was then moved on rollers to the centre of the square formed by the intersection of the transept, and the main avenue, whence it was hoisted; all the ribs were landed over this square, and were after-

FIG. 47.



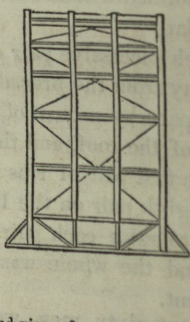
Section through the transept, showing the arrangements for hoisting the semicircular ribs. The dotted lines indicate the various positions of the ribs during the hoisting.

FIG. 48.



Plan of centre of transept, showing the position of the crabs for hoisting the ribs, &c.

FIG. 49.



End view of a pair of ribs, framed together, previous to being hoisted.

wards moved on a tramway to their permanent positions. This tramway, formed of half balks, was constructed over the columns on each side of the transept, at a height of about 4 feet above the lead flat.

The hoisting tackle consisted of four crabs, each one being

placed on the side of the transept, opposite to the part of the ribs to be lifted by it, so that the men at the crabs might watch the effect of their exertions with greater convenience. The hoisting-shears were placed on the lead flat, immediately over the deep trusses of 72 feet span; each set consisted of three stout scaffold-poles, lashed together at the top, bearing on planks laid across the flat, and secured by the necessary guy-ropes. The hoisting rope passed from each of the crabs, across the transept to a leading block attached to the foot of the column in the opposite angle of the square; it then passed up to a treble block attached to the shears, and from thence down to a double block, secured by chains, to the bottom part of the ribs. The extreme width of the frame-work to be hoisted was 74 feet, and the clear width apart of the trusses, above which it had to be hoisted, was only 71 feet 4 inches; it was, therefore, necessary to raise one side to a height of 35 feet, before lifting the other, so as to diminish the horizontal width. The diameter of the semicircle being maintained at this angle, the whole was then hoisted, until the highest end could clear the tramway. The foot of the ribs was then passed over the tram-way, high enough to allow the other side of the ribs to clear the opposite truss, after which the whole was hoisted to the full height, and rested on rollers of hard wood, placed between the cills attached to the framework and the tramway, by means of which it was moved to its permanent position. There it was again raised by another set of shears, while the cill and tramway were removed, and the ribs were then lowered into the sockets prepared for them, which, in fact, formed a continuation of the columns above the level of the lead flat.

Each successive pair of ribs was fixed at a distance of 24 feet, or one bay from the preceding one, and the purlins, &c., were placed in this space by means of jointed ladders, which were adjusted to the form of the roof, and thus all scaffolding was avoided.

The first pair of ribs was hoisted the 4th of December, 1850, and the eighth pair on the 12th of the same month. It took about one hour to raise each pair, from the ground to the level of the lead flat, and the whole was completed without the occurrence of any accident.

About sixty men were employed in the hoisting, there being eleven men to each crab, and the remainder engaged on the lead flats.

Conclusion.

In bringing to a close this somewhat lengthy description, the Author cannot but express his sense of inability to cope with the vastness of the subject, and the importance of its scientific details.

He cannot, however, better conclude, than by reminding the members that the weight of responsibility, the arduous duty of supervision, the honour of acting as the master mind, to weigh the requisites, to determine the design, and to govern the construction of this great apparatus, have been reserved for Mr. Cubitt, President of the Institution of Civil Engineers.

The paper is illustrated by a large collection of working drawings and diagrams, borrowed for the occasion, from which the woodcuts are compiled.

Mr. VIGNOLES thought it was incumbent on the meeting to offer their best thanks to Mr. Digby Wyatt, for the able manner in which he had treated this interesting subject, and for bringing it to the Institution; but he thought that the last paragraph of the paper required some explanation. It must have been observed, that in mentioning the different gentlemen who had been connected with this undertaking, the name of Mr. Paxton had scarcely received due consideration; this should not have occurred, as to that gentleman was due the credit of having originally proposed this unique design, for which the Royal Commissioners had discarded their own plan, upon which so much time had been spent, and in the arrangement of which no doubt considerable expense had been incurred. He thought that the omission now complained of should be repaired. He was not, until then, aware that the President was so intimately connected with the design, or the execution of the building; yet he trusted that these remarks would not be viewed as being dictated with the intention of questioning the value of the President's counsel and guidance, the importance of which must be universally admitted.

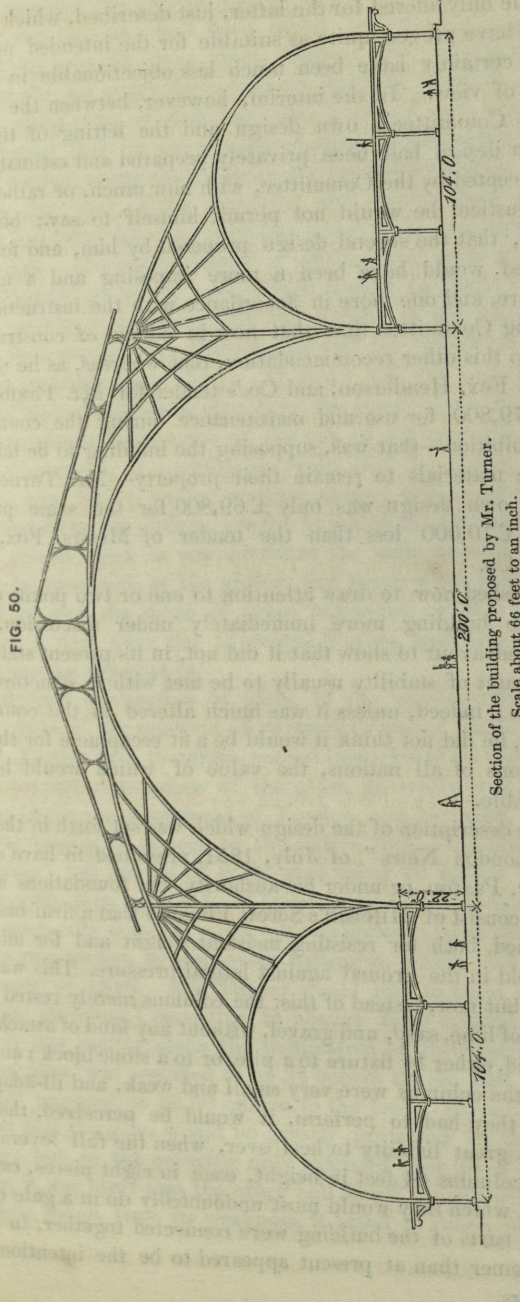
Mr. DIGBY WYATT said, he had distinctly stated in the paper (page 8), that to Mr. Paxton was due the merit of having proposed the original design, and to Messrs. Fox and Henderson must be given the credit of having suggested many improvements in the details of its construction. It was barely justice to mention, even more strongly than had been done, the great services rendered by Mr. Cubitt in undertaking so much of the labour of the supervision of the details of the proposed construction, and of the general matters connected with the building; in fact, it should have been stated more distinctly that Mr. Cubitt was the authority from whom all orders emanated, and to him every question was submitted for his decision; it was, therefore, only literally correct to say, that his was the "master mind" in the affair, and in fact, Mr. Wyatt felt

assured that not one word more had been said relative to Mr. Cubitt than his actual position justified.

Mr. TURNER said, that it was well known how deep an interest he had taken in the subject, from the first promulgation, in the Autumn of 1849, of the grand idea of an Exhibition of the Works of Industry of all Nations. He had fully concurred in the opinion, that a building should be provided worthy of the high mechanical skill of this country, and commensurate with the enlarged nature of the undertaking. He had, in conjunction with his Son, designed and constructed a model of a structure, which he had the honour of submitting to the Royal Commissioners at their third meeting, January 24th, 1850, at which meeting a Committee for all matters relating to the Building was first appointed; but as this Committee very properly considered, that the acceptance and adoption of any one person's design, without competition, was not in accordance with the spirit and nature of the whole undertaking, it was announced that as soon as the site could be definitely settled, suggestions would be received from all parties as to the general arrangements of the building.

At this competition, Mr. Turner brought forward a second design (Fig. 50), adapted to the ground to be occupied by the building. This new plan consisted of a long parallelogram, intersected at the centre of its length by an arched transept, carrying a dome. In cross section it was semi-elliptical externally, but formed three avenues, or spans, internally, thus having only two rows of supports between the sides. The extreme height of the central avenue, and consequently of the building, was 100 feet, and the width, or span of this avenue was 200 feet; that of each of the side avenues was 104 feet, making the total width of the building 408 feet. It was to have been constructed entirely of iron and glass, so as to be of perfectly uninflammable materials, as laid down and required by the Building Committee, in their schedule of instructions to parties intending to submit designs. The framing of each avenue consisted of a semi-circular rib of wrought-iron, and between them there was a standard of the same material, against which they abutted, and which formed a support for the rib of that portion of the roof between the apices of the two arches. This design, however, along with those of the two hundred and forty-four other competitors, was rejected, and the Committee thereupon made a design of their own, the construction of which was also offered for public competition. The tenders for this contract were received on the 8th of July, 1850. In this competition, he (Mr. Turner) also engaged; but that he might not be accused of inconsistency, in tendering for a design so different in character from his

FIG. 50.



Section of the building proposed by Mr. Turner.
Scale about 66 feet to an inch.

own, he only offered for the latter, just described, which he believed would have proved quite as suitable for the intended purpose, and would certainly have been much less objectionable in many other points of view. In the interim, however, between the publication of the Committee's own design and the letting of the contract, another design had been privately prepared and estimated for, and was accepted by the Committee, with how much, or rather with how little justice, he would not permit himself to say; but he must submit, that the second design proposed by him, and for which he tendered, would have been a more imposing and a more stable structure, and one more in accordance with the instructions of the Building Committee than that now in course of construction. It had also this other recommendation, that whereas, as he understood, Messrs. Fox, Henderson, and Co.'s tender for Mr. Paxton's design was £79,800 for use and maintenance during the continuance of the Exhibition—that was, supposing the building to be taken down, and the materials to remain their property—Mr. Turner's tender for his own design was only £69,800 for the same purpose, or exactly £10,000 less than the tender of Messrs. Fox, Henderson, & Co.

He wished now to draw attention to one or two points connected with the building more immediately under discussion, and he would endeavour to show that it did not, in its present state, possess that amount of stability usually to be met with in structures of iron and glass; indeed, unless it was much altered in the course of its progress, he did not think it would be a fit receptacle for the various productions of all nations, the value of which would be almost incalculable.

In the description of the design which was set forth in the "Illustrated London News" of July, 1851, presumed to have emanated from Mr. Paxton, or under his authority, the foundations were proposed to consist of Mitchell's Screw Piles, so that a firm basis would be obtained, both for resisting insistent weight and for affording a secure hold in the ground against lateral pressure. This was a main feature; but now, instead of this, the columns merely rested on some concrete of lime, sand, and gravel, without any kind of attachment to the ground, either by fixture to a pile, or to a stone block; and as the bases of the columns were very small and weak, and ill-adapted for the duty they had to perform, it would be perceived, that there must be a great liability to heel over, when the full leverage of a series of columns 64 feet in height, each in eight pieces, came into operation, which they would most undoubtedly do in a gale of wind, unless the parts of the building were connected together, in a more secure manner than at present appeared to be the intention of the constructors.

Then, as regarded the girders supporting the galleries, it was not sufficient to say, that they had been tested far beyond any weight which could be brought upon them, because the testing of the girders alone did not prove their ultimate stability when in place, resting on a small snug of only five cubic inches of cast iron. It was to be feared that on the passing of great numbers of persons, all in one direction, along the galleries, an undulatory motion would be given to that part of the structure, and would cause a fatal accident, as had been the case, from the same cause, on many suspension bridges. He was decidedly of opinion that these galleries should be subjected to severe tests, which should be made to correspond, as nearly as possible, with the weight of the number of persons likely to occupy the galleries, and with the velocity at which they would probably pass along. If there was any objection to this mode of testing the whole structure, the snugs alone might be tested by the simple application of the ram of an hydraulic press; but he would suggest, as a preferable mode, that the girders should be tested *in situ*, whilst resting on these snugs; this could be done by suspending from the girders, cradles in which the testing weights would be placed; and he was confident the same amount of load would not be sustained, as the girders had borne when tested separately. This was the mode of proof suggested by Mr. Fox for Mr. Turner's roof over the Liverpool Station, and, therefore, it could not now be objected to.

The universal application of glass, in the construction of this building, rendered the question of its strength one of grave importance; Mr. Turner had, therefore, caused inquiries to be made, as to the thickness and dimensions of the glass, generally used for conservatories in the neighbourhood of London, and he found, that the weight was usually 16 ounces to the square foot,—the same as in this building; but instead of each pane being 49 inches long by 10 inches wide, they were only 24 inches long by 7 inches wide, and in some cases only 6 inches wide. Nevertheless a large quantity of this glass was broken by the severe hailstorm, which took place in the Summer of 1846. Mr. Turner would like to know what had caused the Building Committee to change their opinion so completely on this matter, since the publication of their own plan, in which the glass was specified to be 24 ounces to the foot, and was afterwards required to be 30 ounces to the foot. However, it had been said that the glass would be greatly protected by the canvas covering; but, as the covering only extended over one-half of the building, it was clear that the other half would remain without that protection, which, from its weakness, it stood so much in need of.

He denied that there was any absolute reason for using a canvas covering, because had dim-coloured glass been used, such as he proposed, the rays of light would have been quite as effectually subdued, without having recourse to this slovenly, and, positively, dangerous contrivance, which, he thought, would be found to seriously militate against the presumed beauty of the Crystal Palace.

It could not be denied, that there existed great liability of accident from fire in this building, which really seemed to be constructed for the express purpose of perishing in a conflagration, if one stall should happen to catch fire. This was another point in which the present building differed materially from the instructions laid down by the Building Committee, and also from the plan which they drew up, in both of which all the materials to be used were required to be "fire-proof," so that the progress of any fire might be easily arrested, and its ravages be limited to the spot where it broke out. This departure from the original plan was unwarrantable, and could not be defended on any grounds. The Commissioners, by not adhering to the original terms of the specification, and providing "a fire-proof building free of rent," had broken faith with the public; he understood, that the building was still uninsured, and, perhaps, might continue so; and as he supposed, that the Commissioners did not intend to become individually, or collectively responsible to the exhibitors, for any accident which might arise, either from fire, or otherwise, the exhibitors would have no remedy but to endeavour to effect an insurance each for his own articles, which could only be done by a much larger outlay than would have been incurred for ordinary rent in a really fire-proof structure; on these and many other grounds, which the limits of a discussion at the Institution precluded him from entering on, he called on the members to consider the question carefully, and to record the resolution at which they should arrive.

Mr. Scott Russell said that he felt a deep interest in the building in Hyde-park, both officially and personally, but as, from the commencement, he had never had the slightest connexion with it professionally, nor taken the smallest responsibility in reference to its construction, he might be permitted to speak disinterestedly, not as Secretary to the Commission for the Exhibition of 1851, but simply as a member of the Institution. These introductory words were not, however, intended to shelter himself from responsibility; on the contrary, he should be proud if he was able to claim the slightest share of the responsibility, or the merit of anything, either in the design, or in the details of the construction, connected with the building.

From what Mr. Turner had said, it might be assumed, that he did not comprehend the principles on which this structure depended, and from which it derived its wonderful combination of stability with lightness. Mr. Turner had stated, as his chief reason for doubting the stability of the structure, that it was merely based upon gravel concrete, without attachment to the ground, and that the columns were so placed, that if such a degree of obliquity was given to one of them, that its centre of gravity should be extended 2 inches, or 3 inches beyond the base, the whole structure would topple over like a pack of cards, and fall prostrate. He quite agreed with Mr. Turner, that such a pressure as 50 lbs. on the square foot, which had been mentioned, would overturn the building, if it were really constructed as was supposed.

Many railway stations depended for their stability on the mode of fixing the base of the column, but to them the present structure had not the slightest analogy; indeed, it was so totally different, that, instead of the falling of one column having any tendency to bring down the next, he believed if one was knocked to pieces it would not at all affect the neighbouring one, but the two next would so completely support the structure that the loss of the one would not be felt; this had actually occurred; a pillar had been broken, and its loss had not produced the slightest effect. Being a series of squares, if an accident occurred to one square, the broken girder, or column would be supported by the pressure and tension of the surrounding square. In illustration, then, of the true principle on which this building was constructed, he would refer to the case of a four-legged table, which was neither supported on stone, nor concrete, nor bolted to the floor; and although a single leg standing alone would certainly topple over, yet the manner in which the four were united gave the strength. He considered such a table as a type of the building, and a glance at the transverse section would satisfy any one of the fact, that the building was made up of a continuous repetition of a structure and framing of the nature of that table. The entablature which united the columns at the top, was firmly attached to the upright pillars, in the same manner as the frame of the table was attached to each leg. It was the top frame which preserved the leg in its upright position, and just in the same manner as the table was firm, although its legs were not attached to the floor, was this building secure and stable, although the columns were not inserted into the ground.

There were thirteen pillars in the cross section, and eighteen cross wrought-iron girders, every one of which must be broken from its attachment, or be fractured, or have the pillar cut away from under it, before the building would yield to the pressure of the

wind. It was obvious, therefore, that there was such an accumulation of strength as he believed could not be found in any other building of a similar nature, and decidedly greater than was at all necessary to resist any forces, elemental, or otherwise, that were ever likely to act upon the building.

Mr. PAXTON thought it right to explain to the meeting that when his design was accepted, it was ordered that Messrs. Fox, Henderson, and Co. should submit the working-drawings to Mr. Cubitt (President Inst. C. E.) for his approval. A tabulated form was then drawn up of the weights of every part of the structure, of the test to which each part should be subjected, the calculated breaking-weights, and, indeed, of all the details of construction. These calculations were further tested by careful experiments made at the works of Messrs. Fox, Henderson, and Co., near Birmingham, so that every precaution had been taken to insure perfect safety. Those gentlemen were quite ready to give any information as to the stability of the structure, and he would be happy to answer any questions that might be asked, relative to the principle of the ridge and furrow roof, to the open flooring, and to the system of ventilation.

As it had been asserted, that the glass used in the building in Hyde Park was not of sufficient strength—he would reply, that the glass used in the great conservatory at Chatsworth, which had now been erected ten years, weighed only 15 ounces to the square foot; the length of each pane was only one inch less than that used in this building, and the ends were oblique, which would have the effect of weakening it, and yet not a single pane had been broken by any hail-storm which had taken place during that number of years. The canvas covering, as well as affording great protection to the glass, would keep out the sun-rays and subdue the intense light, which might be objectionable; and it would also, as had been explained by Mr. Digby Wyatt, be of essential service for producing ventilation during the summer months. It should be understood that the canvas covering was in detached pieces, each piece extending only from ridge to ridge, so that if one piece did happen to catch fire, as had been suggested, the flames could not by any possibility be communicated to the other portions of the canvas covering, and consequently that piece only would be burned.

As to the effect of snow, he could only say that at Chatsworth it had been sometimes twelve inches thick on the roof, without being productive of any injury.

Mr. C. H. WILD remarked, that his connexion with the building had enabled him to become intimately acquainted with all the practical details of the structure, as well as with the calculations that

had been previously made for determining the strength of the different parts, and also with the experiments that had subsequently been made to test the correctness of these calculations. He was, therefore, in a position to speak positively on these points, not as a matter of speculation, or mere conjecture, but as stern facts, and he would endeavour to examine each part seriatim.

First, with regard to the foundations, to which great attention had been devoted, borings were very carefully made over the whole of the site, which was found to consist of gravel of the most compact kind. The holes were filled up with concrete of even a sounder quality. This was tested to the extent of 7 tons per square foot without crushing, or being otherwise injured. And as, by calculation, it had been found that 2½ tons was the utmost that could ever be brought to bear on each square foot of foundation, supposing the galleries and every part of the building to be crowded with visitors, and the roof to be covered with 2 feet of snow, he thought they had kept well within the mark.

Before determining the thickness of the columns, careful calculations had been gone into, as for the foundations, to ascertain precisely the weight which each would have to bear under all the circumstances of the building. The thickness of the metal of the weakest column, which had only to support half of a 24 feet bay of roofing, was ½ inch, and it varied from this to 1⅛ inch, which was the thickness of the strongest column of the nave, upon which the actual weight would only be 60 tons, whilst its breaking-weight was 306 tons.

It was impossible to calculate what the snugs which supported the girders would really bear, but he thought that they were so strong (in fact the strongest part of the building) that it was perfectly ridiculous to raise a question about them.

The girders had all been proved to double the greatest weight that could ever be brought upon them, and their breaking-weight was double that of the testing-weight, so that they were four times as strong as any weight they would ever have to bear. The same law did not apply to the roof-trusses, which only had to support the actual weight of the roof and the snow which might happen to fall upon it. He had before stated, that in all cases a thickness of 2 feet of snow had been allowed for, and he believed every one would admit that to be an allowance amply sufficient to meet all contingencies. The weight of the roof, together with that of the snow which each truss would have to support, was not equal to two-fifths of the test that had been applied, and which the trusses had borne and recovered from,

without alteration, or without acquiring any permanent set. The glass had been proved, by the experience of some years at Chatsworth, to be amply strong enough for resisting more inclement weather than generally occurred in a winter season in London, so no fears need be entertained on that account.

Mr. HEPPEL said he had listened with much attention to the paper, and to the observations which had been made by the different speakers, but as there were still one or two points on which more explicit information seemed to be required, and which, no doubt, those immediately connected with the building could supply, he would venture to offer a few remarks.

He thought Mr. Scott Russell's illustration, comparing the principle on which this building was constructed to that of a four-legged table, was extremely clear and instructive. He would, therefore, assume the same position, and would further suppose, for the purpose of this argument, that a line of trusses extended completely across the building, at a height of 20 feet above the floor-level, or at the heads of the lower columns, in the precise position now occupied by the girders of the galleries, and would then ascertain what amount of strain would be brought upon these lower columns, by the action of the wind on the two upper stories, neglecting for the present its action on the lower story, and compare this strain with their ultimate strength.

The interval between each transverse assemblage of columns being 24 feet, and the height of the two upper stories together being 40 feet, the surface corresponding to each set of columns in the lower story would be 960 square feet, and supposing the force of the wind to be 50 lbs. per square foot, there would then be a horizontal force of 48,000 lbs. on each transverse assemblage of columns in the lower story. This force would clearly be discharged on the heads of these columns, and would act in the same way as if the whole lower story was a table with thirteen legs, and the top of it was pushed with this force. In such a case, it was a matter of indifference whether the legs were attached to the ground and the top of the table was pushed, or whether the top of the table was the fixture and the force was applied in the opposite direction, perpendicular and transversely to the legs. In the latter case it would act on them as on so many tubes solidly fixed into a wall at one end, and projecting their whole length, which would here be 18 feet; and as the strain would be divided equally amongst them, it would, in this instance, amount to one-thirteenth of 48,000 lbs., or 3,700 lbs., or 1·65 ton upon each.

Now, in Mr. Edwin Clark's Treatise on the Britannia and Conway Tubular Bridges,* the breaking weight of a cast-iron tube, 6 feet in length, $3\frac{1}{2}$ inches mean diameter, and having a sectional area of 4·12 square inches, supported at each end, and loaded in the middle, was 2·287 tons. Half this quantity, therefore, or 1·143 tons, would be the breaking-weight of a tube 3 feet in length, fixed in a wall, and loaded at its extremity. And since the breaking weight of tubes was shown to be proportional to the function $\frac{a\,d}{L}$ (where a was the sectional area in square inches, d the mean diameter, also in inches, and L the length in feet), it might be inferred, that the breaking-weight of a tube of the average strength of these columns, 18 feet in length, $7\frac{1}{4}$ inches mean diameter, and having a sectional area of 17 square inches, would be 1·628 tons.

He had before shown, that a force of 50 lbs. per square foot, on the surface of the two upper stories, would bring a strain of 1·65 tons on each column in the lower story, tending to break these columns at their necks. This was a strain which exceeded the calculated breaking-weight; and although the force of the wind might never amount to 50 lbs. per square foot, it was obvious, that whenever it exceeded one-quarter of that amount, the strain on the necks of the columns in the lower story would approach nearer to the breaking strain than most engineers considered to be consistent with safety.

From the experiment before mentioned, the probable deflection of these columns might also be ascertained. It appeared that the tube used in that experiment deflected ·28 of an inch, with a weight of 21 cwt. applied at its centre; if the tube had been half the length, and had been loaded with half that weight at its extremity, the deflection would, at least, have equalled that amount. The deflection of tubes was well known to vary as the function $\frac{W\,l^3}{a\,d^2}$, (where W was the weight applied in cwts., l the length in feet, a the sectional area in square inches, and d the mean diameter, also in inches); therefore the deflection of a tube situated like these columns, and under the same circumstances, with a force of wind of 50 lbs. per square foot, would at least amount to 10·8 inches, which might be termed the breaking deflection, and for any other force of wind it would vary in direct proportion, increasing about 2 inches for

* *Vide* "The Britannia and Conway Tubular Bridges: with general inquiries on beams and on the properties of materials used in construction. By Edwin Clark. Published with the sanction and under the supervision of Robert Stephenson. 2 vols. 8vo. Folio atlas of plates. Lond. 1850;" vol. i. page 430.

every 10 lbs per square foot. Mr. Heppel would be glad to know whether such an amount of deflection was anticipated.

With regard to the effect of expansion and contraction on the long line of girders, by the variation of the temperature, he would cite the opinion of Tredgold (almost the only good authority on the subject),* that in this climate the variation in the length of cast-iron bars exposed to the sun—and it was fair to presume that the girders in this building would be so exposed—amounted to $\frac{1}{1270}$th of their length. This in a length of 1,848 feet would amount to about 18 inches; but as this building was intersected by a transept at, or about, the centre of its length, the half of this, or 9 inches, would be the variation in length of each portion; and supposing all the girders to have been fixed at a mean temperature, and their junction with the transept to be firm and stationary, each extremity would oscillate, or shift in position, 9 inches, or 4½ inches, on each side of its mean, or original position. This consideration seemed of itself to exclude the possibility of supposing a rigid connexion between the bases of the columns and the ground; as in that case the breaking deflection would only amount to one-quarter of what it would be on the supposition of the bases being free to oscillate, or less than the distance through which the heads of the columns would, by the expansion and contraction, be made to traverse.

Mr. Heppel therefore considered they were in this dilemma, either that if, as in Mr. Russell's supposition, the bases of the columns were supposed not to be rigidly connected with the ground, but to depend on the rigidity of their union with the superstructure, then their strength was not so much in excess of the possible strain which might be brought upon them, as was usually deemed necessary for perfect security; or, on the other hand, if a rigid connexion at the bases was supposed, then there would be danger of fracture, by the motion induced by the expansion and contraction of the girders.

In offering these remarks, he wished it to be distinctly understood, that they were not made as criticisms on the work, but rather as an exposition of the wants of those members who, like himself, only knew this, in many respects, admirable work, from the description given in Mr. Digby Wyatt's paper, and the remarks which had been made upon it. He would listen with the utmost attention to such further explanation as any gentleman better informed on the subject

* *Vide* "Practical Essay on the Strength of Cast Iron, and other Metals, &c.; containing practical rules, tables, and examples, &c. 8vo. 2nd edition. By Thomas Tredgold. Oxford, 1824," page 272.

might be disposed to give, and with the strongest desire to be convinced of the sufficiency of every part of the building.

Professor Airy said he had listened to the abstract of Mr. Wyatt's paper, and to the discussion on it with much interest, and would remark, that he was following, in a great measure, the gentleman who had last spoken; at the same time he thought some elements of calculations might be altered, and the general considerations be put in a different form. He had no intention to criticise, in any degree, the general plan of the building. He joined in opinion with the great mass of persons who had considered that, in its general structure, as intended for a specific purpose, it was admirable, and that nothing could exceed the skill displayed by those who were immediately intrusted with the erection. He would confine his observations to those parts of the structure having immediate reference to its strength, and if he objected to some things which, in his judgment, did not appear sufficiently strong, he did so not for the purpose simply of finding fault with them, but with this view, that if it were judged expedient to make alterations, although late, there was probably yet time to make them.

In considering the general plan of the building in Hyde Park, the first thing which must strike any one who examined it with reference to its strength was, that the world had never seen such an instance of a purely rectangular structure. He was aware of the extent to which this principle was carried, in the Lancashire mills, and in buildings of that class generally; but in all those places, where vertical columns supporting rectangular combinations of beams were carried up story after story, there was an ultimate resource of strength, in the tying of those beams into the walls, and in the connexion of the side walls with the strong end walls. Those structures, therefore, depended for their strength and stability, on considerations entirely different from those which applied to the glass building in Hyde Park.

In order to estimate, whether a structure of the present kind was competent to resist such forces as might be expected to come against it, he would first take into consideration the force of the wind, and the grounds of his calculation were these: it was well known that in this part of the country there might be expected, once, or twice a-year, gales which have a singular uniformity in their maximum pressure, rising from about 20 lbs. to 25 lbs. on the square foot.

It might be given as a good practical rule, that a square of building sustained about a ton of pressure from the wind. He would, therefore, take one of the transverse frames of this great building,

and consider how much of horizontal pressure it would have to bear from the wind. The breadth which had to be sustained by that frame was 24 feet, the height above the ground being about 66 feet; multiplying these together, it would be found, that the portion of a side exposed to the wind, which was supported by that cross framing, was about 16 squares, or sustained a pressure of 16 tons, acting horizontally, at a mean height of 33 feet. For the present he would put aside all considerations of the stiffness of the columns, and consider merely the effect of the girders, which were hooked at their upper and lower edges into the snugs cast on the columns. When girders acted as these did, resisting any tendency to the inclination of the columns, by the thrust of the upper edge and the pull of the lower edge, or *vice versâ*, their action became that of, what was called in theoretical mechanics a "couple," and then it was well known that their position, in regard to absolute height, was a matter of no importance in resisting the tendency to fall; the only thing on which the resistance depended was the depth of the girders. The depth of these girders was 3 feet. Here there was a pressure of 16 tons acting at a mean height of 33 feet. If that were resisted by a single girder hooked on at one end only, the depth of that girder being 3 feet, that hook would sustain a pressure of about 180 tons. But, when there were in the same frame a number of girders, all receiving the same motion at their points of attachment, —when the form of the frame was sensibly strained (as it was in the building in Hyde Park), this pressure might be considered as divided equally among all the different points. Now there were seventeen girders in the whole frame, giving thirty-four breaking points; the pressure being 180 tons to be divided between thirty-four points, it followed, that there would be, on every one of those hooks, a pressure of between 5 tons and 6 tons; and if any one of them broke, there would be a corresponding increased pressure on all that remained. It was a question for practical men, whether the strength of the hooks, or snugs (which were of cast-iron), was sufficient to resist such a strain; he confessed he had doubts on the point; he did not think them sufficiently strong; and considering this as the main support of the building, he did not, in his deliberate judgment, think the strength was sufficient.

It was quite true that there was another thing tending to support the building, namely, the stiffness of the columns, as planted on the ground, independently of the support which they received from the girders. A column might give way, under the effect of a horizontal thrust, either from the column itself breaking, or from its joints breaking, or from its foundation-piece being turned over on the

ground. He had no fear of the columns breaking; he should be much more inclined to expect that the joints might break, by the fracture, or stripping of the flange-bolts. But those parts, in his opinion, were much stronger than the method of foundation; the base-plates were small, and merely rested on a mass of concrete, without being attached to the ground, so that a very trifling force would suffice to tear them up, or rather to turn them over, on any divergence of the columns from the perpendicular. He therefore thought himself justified in referring, as he had done, to the girders only for the strength of the building.

In alluding to the foundation-plates, and the beds of concrete upon which they rested, he thought it proper to remark, that he had heard some expression of doubt as to their competency to resist the vertical pressure which would come upon them. He had, however, no doubt of that kind himself; the only part in which he thought them weak was, in their inability to resist an uprooting, or overturning force.

It would be observed, that since the design of the building had been originally formed, a number of diagonal stays and ties, had been introduced into various parts; as far as he could ascertain, from the information he had received, the space between one of those diagonals and another, measured along the length of the building, amounted to 192 feet. There was, therefore, 192 feet left undefended, except by the support it received from the diagonals at the end, which gave little strength to the intermediate part. For there was no bracing-support between, even in the arrangement of the planking of the floor, and it was quite conceivable, that when the wind blew violently, the parts intermediate between these diagonals might be blown down, leaving in a standing state the frames which were strengthened with diagonals.

The calculation, which he had submitted to the Institution, supposed the building to stand quietly resisting the action of an unvarying pressure. But it was not thus that the greatest injury was commonly inflicted. When the wind blew in gusts, or even when crowds of persons were moving about, a building constructed with so little regard to stiffness would be put in a state of vibration, and at one of the largest vibrations some hook, or snug, which had been wedged up tightly, and had borne the principal pressure, would probably give way, and when this had happened, it might be expected that in the following gusts the hooks would break *seriatim*. He could not entertain any belief that the building would endure for a long time. To strengthen it, he would suggest the addition of diagonal tie-bars through every or nearly every transverse frame,

tying the tops of the columns next the middle avenue, with points of the external columns near their foundations, and connected with every column and girder which they passed; if that plan was adopted, he thought considerable extra strength would be given to the building. It would also be proper to insert diagonals in the longitudinal framing.

Professor Airy concluded by adverting to instances, principally connected with the mounting of astronomical instruments, in which he had occasion to remark the astonishing difference of firmness between a rectangular frame, having broad flange bearings at the bottom, and girder connexions at the top, and another frame of far lighter materials, and with no strength of joints, but planned on the triangular, or braced-rectangular arrangement of bars.

Mr. Joseph Freeman suggested whether the force of the wind, if so great as had been stated, would not break the glass, or force in the sash-bars, before it operated injuriously on the framing of the building.

Major-General Sir C. W. Pasley thought, that no injury could take place from vibration, or, more properly speaking, from undulation, in a rectangular building like that in Hyde Park, which resembled a bridge on piles, or piers, and was not at all analogous to a suspension-bridge. The effect of troops marching regularly in step over a suspension-bridge, produced, not a vibration, but an undulation, from which at least one serious accident had resulted in France, and he believed another had occurred in the north of England; but in the building under discussion, there were really no elements of undulation, and, therefore, no reasonable fears of accident arising from that cause could be entertained.

Mr. A. J. Robertson trusted that, as so young an Associate, it would not be considered presumptuous in him to address the Institution, on a subject of so much importance as the stability of the building for the Great Exhibition; but as he conceived one principal point had not been alluded to, he ventured to submit for consideration a few observations.

It was a received axiom in construction, that proportion was perfect, when all the parts of a structure yielded simultaneously to a force which was sufficient to break one of them. In the structure under consideration this principle seemed to have been followed in the cast-iron girders which united the columns, so far as their capability of bearing weight was concerned.

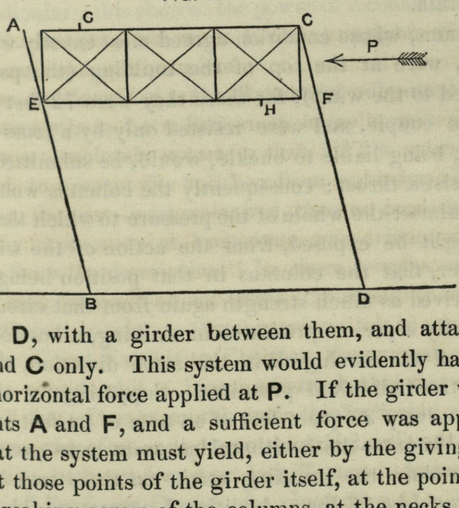
But when a structure had to resist more than one force, or set of forces, independent of one another, it was evidently impossible to adjust the proportions in such a manner as to cause this condition to

obtain with respect to all. Hence it was necessary to take the weakest point, and the amount of resistance it was capable of offering, as a measure of the stability of the whole.

There appeared to be no cause for doubt, as to the strength of the columns for supporting weight, provided the castings were sound; but as regarded transverse strain, the case seemed not to be so clear.

Mr. Scott Russell had justly compared the square, formed by four columns, to a table, the legs of which must be broken, before it could be overturned; but in order to ascertain the exact value of this stability, it was necessary to calculate the transverse strength of the columns. Again, since the stability depended entirely on the girders, there being no fastening at the bottom of the columns, and the size of the base plates being insignificant in comparison with the height, it was necessary to ascertain the power they possessed of offering resistance to a horizontal force. Suppose two columns,

FIG. 51.



A B and C D, with a girder between them, and attached at the points E and C only. This system would evidently have no power to resist a horizontal force applied at P. If the girder was attached at the points A and F, and a sufficient force was applied, it was evident, that the system must yield, either by the giving way of the fastening at those points of the girder itself, at the points G and H, or by the breaking across of the columns, at the necks E and F.

The flanges of the girders not having so great a sectional area as the snugs, these snugs would not be the first to yield, if the metal was sound. Here it is necessary to inquire, whether there was not some risk of the keys, which were the only fastening, working loose, when vibration was communicated to the building, or whether means had been adopted to prevent this.

The area of the section of the girder at G was stated to be 3·9 square inches; at H it was 4·89 square inches; G would therefore be the first to yield. Moreover this strain was tensile, therefore the

force necessary to break the flange, would be about 28 tons, and the pressure to be applied at the foot of the column would be $\frac{3 \times 28}{20} = 4$ tons.

From experiments made by Mr. John Hosking for Mr. R. Stephenson, and given by Mr. Edwin Clark in his account of the Britannia Bridge,* it appeared, that the force applied at the foot of a hollow column 21 feet long, 8 inches in diameter, and ¾ of an inch thick, was 1·16 ton, and this was the reaction of an equal force, applied at the level of the girder; the neck of the column was therefore the weakest part. The horizontal force, therefore, necessary to break down a couple of columns was 2·32 tons, and if distributed over the length, as in the case of wind, the force would be 4·64 tons.

Taking the area exposed, which was supported by one couple, at 24 feet by 20 feet, equal to 480 square feet, it would be necessary to have a pressure of only 21½ lbs. per square foot to produce the breaking strain.

The columns, whose condition agreed most exactly with the above assumption, were at the top of the building (the part moreover most exposed to the wind), for there they were 72 feet distant from the opposite couple, and were resisted only by a truss of wrought-iron, which, being liable to buckle, would, he submitted, have little power to resist a thrust: consequently the columns would be left to bear alone, almost the whole of the pressure to which that side of the building might be exposed, from the action of the wind. It was true, however, that the columns in that position being fastened at the base, derived as much strength again from that circumstance.

Undoubtedly a person produced in walking, a horizontal thrust, and if a crowd was moving all in the same direction, the total was the sum of the individual pressures. Supposing for this estimate one person to every 3 square feet of an area of 24 feet square—that borne by 2 columns—the horizontal pressure to be exerted by each person, to produce the breaking strain on these two columns, or 2·32 tons, would be 27 lbs. Additional support would, to a certain extent, be derived from the continuation of the columns upwards, and this dead pressure could not be exerted.

* A cast-iron tube, 4 inches in diameter, 3-8ths thick, and 6 feet between the supports, on an average of three experiments, broke with 2·287 tons in the centre; had it been supported at one end, and weighted at the other, it would have broken with $\frac{2 \cdot 287}{4} = \cdot 57$ ton; and as similar hollow cylinders of the same length have a transverse strength, varying on the cube as the diameter $\frac{2^3 \times 6 \times \cdot 57}{21} = 1 \cdot 16$ ton, the breaking weight of the column.

Danger, therefore, might not, perhaps, be apprehended from simple pressure; but when these pressures were accompanied by motion, and that of an intermittent kind, there might be some risk of a strain being produced by accumulation, far greater in amount, and, being sometimes backwards and sometimes forwards, far more destructive in its effects, than simple pressure. It had been observed with truth, that it was not dead weight which broke down suspension bridges. The same might be repeated of the overthrow of chimneys. If elasticity of material gave such opportunity for the accumulation of pressure, that intensity must be greatly enhanced by any play amongst the several parts of the structure.

As an analogous case it might be mentioned, that when the first part of the centering of the High Level Bridge at Newcastle was put up, and a road was laid down for bringing stone to the first foundation, the friction of the trucks upon the rails, when the breaks were put on, drew the uprights at that time erected, perceptibly out of the perpendicular; this showed the power of a constantly recurring force of small intensity; but when the next uprights were erected, the stability was rendered complete.

From these considerations Mr. Robertson submitted, that supposing the strength to be sufficient to carry weight and to resist pressure, it was absolutely necessary that all the parts should be rigidly united, to prevent the building from becoming ricketty.

If, however, the parts were so united, then no provision appeared to be made for expansion; at least none was evident, either in the drawings, or from the description. In short lengths, or when the variation of temperature was not great, the elasticity of the metal might be sufficient to take up the expansion; but in such lengths as existed in the Great Exhibition Building the amount of expansion must be very considerable. It was admitted, that there might be a thickness of 2 feet of snow on the roof: this indicated a low temperature; it was, therefore, not an extravagant estimate to take 75° as the variation between Summer and Winter. According to the experiments of Professor Daniel, the elongation of a bar of cast-iron due to 75° was ·000446. The length of each division of the building was about 850 feet, and its expansion due to this variation would be $4\frac{1}{2}$ inches. If the two ends were precisely alike, the expansion would of course commence in the centre, and the deflection of the last column from the perpendicular would be $2\frac{1}{4}$ inches; but as there was an additional resistance produced by the circular roof at one end, this division could not be exactly equal.

There were three tiers of girders. If these were of such material that they would expand in proportion to their elevation above the

feet of the columns, the straightness of those columns would be preserved, and no strain would be brought upon them. But these girders would expand alike; the vertical direction and parallelism of the upper part of the columns would consequently be preserved, and the whole deflection be thrown upon the lowest length.

The sum of the sections of the top and bottom flanges of each girder, at the thinnest part, was 8·8 square inches and $8 \cdot 8 \times 3 = 26 \cdot 4$ square inches for the three tiers. According to the experiments of Mr. Hodgkinson, given in Mr. Clark's work on the Britannia Bridge, the compressibility of cast-iron was about double that of wrought-iron, and therefore one ton per square inch would compress it through $\frac{1}{5000}$th of its length. As the above expansion was nearly $\frac{1}{2000}$th, the pressure exerted must be nearly $2\frac{1}{2}$ tons per square inch, and that would give, for the total pressure produced by the expansion of the girders on one line of columns, the enormous pressure of 66 tons; and supposing action and reaction to be equal, this pressure would be exerted upon seventeen columns.

In the High Level Bridge, the principles of the construction of which were similar, in some respects, to those of the structure in Hyde Park, every provision was made for expansion, and yet one piece of railing between two columns had been cracked, evidently by the expansion of the longitudinal girder above: for the crack was wider at the top than at the bottom. In that case it was a matter of no consequence, but was useful, as serving to demonstrate the power of that force whose effects had been so carefully guarded against.

It might therefore be submitted, whether one of two alternatives must not be chosen, taking the building as it was,—either that it must be ricketty from looseness in the joints, or be liable to fracture from the force of expansion.

It was stated, that several operations connected with the moving about of each girder were, together with the testing, performed in the short space of four minutes. It might be asked whether, in testing these girders, the deflection and set (if any) was measured, or whether it had been considered sufficient that the girder did not break under the operation.

The roof-girders appeared to have been tested by the application of a weight, at the points where the bearers rested. The area of floor supported by two gallery girders was 24 feet by 24 feet, = 576 square feet; taking the possible dead weight of a crowd at 120 lbs. per square foot, there might be a load, to be borne by these two girders, of upwards of 30 tons, or the same as the test, if in testing the weight was distributed.

Mr. DOULL would confine his remarks, principally to what he conceived to be the erroneous mode in which Mr. Scott Russell endeavoured to illustrate the subject.

It was dangerous to make a semblance of reasoning from analogy, where no analogy existed; but it was still more dangerous, where the analogy only held good in a few unimportant particulars. This, he submitted, was precisely the case with Mr. Scott Russell's illustration of the principle involved in the construction of the building for the Exhibition, by reference to a four-legged table.

It was true, that a cubical portion of the building had four pillars, and the table had four legs: further, that a cubical portion of the building had four girders connecting the pillars, and the table had four rails connecting the legs; also that the table had a top, and a cubical portion of the building had a roof, or floor.

These, however, were mere analogies of form and parts, and to pass from these analogies of form and parts, to the analogies of strength and stability, was a dangerous delusion. If, for example, a ring bolt was screwed into the centre of the top of the table, so as to suspend it at some distance from the floor, and then the four legs were knocked away, there could be no doubt of the rails remaining firmly attached to the top of the table. If a similar experiment could be tried on a cubical portion of the building, either by using the floor of the gallery, or a portion of the roof corresponding to the table top, in the last experiment there could be no doubt, that the girders would fall to the ground, as quickly as the broken pillars. If the table was supposed to be divested of its top, and there only remained the four legs and the four rails, unless the rails were very deep in proportion to the length of the legs, there would be only a very ricketty structure. Now, the depth of the girders of the building did not bear a very great proportion to the length of the columns, and it was evident, that the top of the table was a far greater source of strength, stiffness, and stability, than the roof, or floor, of a cubical portion of the building.

If one of the legs was knocked away from the table frame, divested of its top, the ends of two of the rails would be liberated; yet it was probable the ends might retain their position, without swagging, or bending downwards to any great extent, unless pressure was used. But if the same experiment was tried with a cubical portion of the building, whether with the 24 feet, the 48 feet, or the 72 feet girders, thus set free at one end, there was no great probability of the girders retaining their horizontal positions; indeed he submitted that, on the contrary, unless there was great lateral pressure, the girders would fall to the ground.

The rails of the table were mortised, glued, and pinned into the legs; the girders were attached to the columns, by simply resting on projecting snugs, and were confined by a small projection; there could, therefore, be no comparison between the firm mode of attachment in the former case and the insufficient plan adopted in the latter case.

The upper projection, or snug, would have brought on to it a tensile strain, which was the worst condition for cast-iron. Admitting that the upper snug would resist the tensile strain thus brought upon it, and that the notch, by which the girder was supposed to be retained in its position, would be sufficient for that purpose, it must be particularly observed, that those projections, or snugs, however strong they might be individually, were attached to very thin hollow columns by a very narrow base, and that the almost, if not quite, universal practice of strengthening projecting snugs, or flanges which had to carry great weight, by brackets either above, or below, had been altogether neglected. Looking, then, at the lower projection, or snug, which would then become the fulcrum of the leverage of the girder, and considering its very narrow base, and its being entirely unsupported by brackets, the probability was, that it would be forced into the column, or be broken from it.

The weakest point of the entire structure was the mode of attaching the girders to the columns; and it must be recollected that this was a vital point, as the existence of the building depended upon these attachments, in the same manner as the strength of a chain, taken as a whole, depended upon the strength of the weakest link, and not upon the strength of the strongest link.

Mr. Doull, therefore, considered the table illustration to be a complete fallacy, and that the principle involved in the construction of the building had yet to be more satisfactorily explained.

Mr. Turner remarked, that Mr. Scott Russell had compared the principle, on which the building in Hyde Park was constructed, to a series of four-legged tables, and had asserted, that as a table would stand, if one of the legs was removed, so would the building in Hyde Park stand, if one of the columns was broken by accident; and he had corroborated this assertion, by stating that this had actually occurred. It was a pity that Mr. Russell did not, at the same time, tell the meeting under what circumstances that column was broken, where and how; also what position it occupied in the building, whether it was in the external row of one story, in the second row of two stories, or in the nave of three stories. But in whatever position it might have been, Mr. Turner contended, that any such conclusions as had been drawn, from a supposed similarity of construction,

when the building was unfinished and untenanted, were perfectly erroneous; it was when the building was occupied and crowded with visitors that the great liability to accident, and of serious results from any accident, would arise. If one leg of a four-legged table was removed, the table might certainly stand, so long as no superincumbent weight was laid upon it, and so, perhaps the building in Hyde Park might stand, under the same circumstances, when one of the columns was removed. When, however, a slight superincumbent weight was placed upon the table, with one leg removed, the table would undoubtedly topple over and fall; and as the most likely moment for a column to fail in this building would be when there was a superincumbent weight bearing upon it, there could be no question that the same result would be produced; that, in fact, the building would come down, and cause a most disastrous and lamentable accident.

Mr. Russell also attempted to show, that the principle on which this building was constructed, differed materially from that of railway stations. Now he contended that this was not true, for there were cast-iron spandril arches in a railway station occupying the same position, and performing the same duty, as the girders did in this building; and it was notorious, that the failure of one column in a railway station caused, in some cases the partial, in others the complete, downfall of the roof. He might cite numerous instances in support of this position; but it would be sufficient to call attention to two accidents which occurred during the past year, one at the Euston Square station and the other at the Bricklayers' Arms station. At the Euston Square station, an engine got off the line, and knocked down a column, which caused the downfall of a large portion of the roof; but at the Bricklayers' Arms station, the failure of only one column occasioned the complete destruction of the shed.

The remarks which had been made by several scientific gentlemen, who had theoretically examined the question of the strength, or rather the want of strength, of this building, were all singularly corroborative of the opinions which Mr. Turner had previously expressed, deduced from his own practical knowledge of the details of such constructions. He had, therefore, now no hesitation in recording his solemn protest against the use of this building, until such time as it had been properly and efficiently tested as a whole, and not in detached portions, or until the building had been braced and strengthened by transverse galleries, and in such other manner as to remove all liability to accident, which now, he felt convinced, would occur. He did not mean to say, that it was not practicable to strengthen the structure in such a manner as to render it safe for the public; but it must be done at such a serious extra cost as

would amount to a positive delusion, as far as the original estimate was concerned.

Mr. Fox said, he wished it to be understood that, so far as he had anything to do with the building, he was anxious to court the suggestions of everybody; he thought it was due to the Commissioners, and to the public generally, that every part of it should be thoroughly considered, so that if any person had the slightest misgivings, with reference to any of the details of the building, they should have an opportunity of stating their objections; and, as the responsibility of maintaining the building rested upon the firm of which he was a member, if any one would point out a feeble part he should feel much indebted to them, because, to say nothing of the disgrace which its failure would entail upon them, the expense would also be a considerable item. He, therefore, wished it to be understood, that at all times he should feel the greatest pleasure in attending to, and endeavouring to meet, any objections which might be raised.

With respect to the strictures as to the strength of the snugs of the columns, he had made the drawing of that part of the structure, and the form and substance had been carefully examined and approved of by Mr. Cubitt. He considered the connexion of the girders with the columns to be one of the most important points of the structure; it required to be so designed as to be capable of bearing, at the same time, a vertical weight and a transverse strain, and that the mode of attaching the girders to the columns should in some cases be rigid, and in others admit of a certain amount of motion to allow for the expansion and contraction, and he conscientiously believed, that the mode proposed was the best that could be devised. On one occasion, during the progress of the building, one of the snugs of the columns was broken off, and the fracture had been patched up with putty, without the fact being reported; the work was carried on in ignorance of the occurrence; the roof was put on; and about a ton and a half of scaffolding was hung to the girder; at last the broken snug gave way, and the end of the girder was left without support, with one end sunk down nearly 6 inches; yet it continued to bear the weight of the scaffolding, although it depended for its support entirely on the strength of the snugs in the other column. In other cases, where by carelessness the men had allowed a girder to slip, it had been broken across the middle, but in no instance had a snug been damaged by an accident.

Professor Airy appeared to consider the foundation of the columns to be feeble and insufficient. In lifting one of the 72-feet trusses, the men let it slip, just when one end only was on the connecting piece, and the other was still out, so that an enor-

mous strain came on two columns, with the girder between them. The effect of this accident was, that instead of being torn asunder at the connecting flanges, they both remained quite perfect at that point, but were broken through the solid metal near their bases. He thought that fact proved the strength of the connexion of the columns with each other, and the soundness of the foundation.

With regard to the thickness of the glass, he believed it to be sufficiently strong, because during the last twelve years his firm had constructed, in England and Scotland, such an amount of iron roofing as required nearly 40 acres of glass, and except in the roof over the slip at Woolwich, they had never used thicker glass than 16 oz. to the foot. In former times, owing to the duty, they had used glass 13 oz. to the foot. Three roofs, which had been the most exposed to the effects of wind, were those of the first-class building-slips, at Pembroke Dockyard, which were glazed with glass of 13 oz. to the foot. The panes were rather wider than those used in the building in Hyde Park, and not more than ten panes had been broken in those roofs during the last seven years. An important element in the strength of the glass was their narrowness; they would bear a heavy hailstorm if only 10 inches wide, but if they were 18 inches in width, they would be very liable to fracture; it was important also, that they should not overlap each other, but that each pane should be quite independent, and fill up an entire space, and no putty should be used except in the fillets.

It had been suggested, that the canvas might take fire, but since that had been mentioned Mr. Fox had put himself in communication with the agent of Sir William Burnett's system of saturation with metallic salts, to ascertain on what terms a permission could be obtained, for using the preparation, which it was understood would effectually prevent such a catastrophe.

Since the greater part of the roof had been covered in, and the southern side had been glazed, there had been a gale of wind which was measured at Greenwich, and was found to have amounted to a force of 22 lbs. per superficial foot, which was within 3 lbs. of the greatest pressure ever known in London. During the height of that gale, Mr. Fox, accompanied by an assistant and one, or two foremen, went on the lead-flat, and took great pains to ascertain if there was any perceptible movement of the building; but beyond such an amount of vibration as would be felt on one side of a column, by giving it a tap on the other side, there was no sensible motion. At the same time, the workmen who had been at work, at the very top of the building, unanimously declared, that they had never felt more motion there, than on the top of any ordinary house in London.

Mr. Apsley Pellatt remarked, that however suitable and appropriate the building in Hyde Park might be for a conservatory, or a winter garden, he certainly did not think it equally so for an exhibition of the varied products which it would have to contain. In his opinion, the strong general light in this building, from the roof and sides consisting entirely of glass, would be found to be exceedingly objectionable, and that it would have been preferable if at least three-fourths of the roof had been covered with slates, and the remaining fourth with thicker glass than that used, and of a different description. It was well known to artists that a redundancy of light was, in many cases, quite as objectionable as too little, and that different aspects produced very different effects. Many objects of an artistic nature would doubtless be exhibited, which would require a very careful and skilful management of light, if they were to be displayed to the best advantage.

He must admit, that he was rather sceptical about the strength of the glass, nor did he think that the canvas covering would afford the protection which was anticipated. When glass was used in narrow lengths, and each pane was well supported, there was really more liability to fracture than when larger panes were used, as the latter would possess a certain amount of elasticity tending to resist hailstorms. It was no argument to say, that because at Chatsworth there had been no accident, there was no liability in the present building; for Mr. Pellatt knew several instances at Staines, where glass of an equal thickness and quality with that used in the Crystal Palace, had been, on two, or three different occasions, destroyed by storms.

He would suggest, that as glass was first manufactured in the cylindrical form and afterwards flattened, it would be better, where great strength was an object, to adopt a system of cylindrical glazing, as in the process of flattening, the inner side of the cylinder was extended, and the outer side compressed, which had the effect of materially weakening the glass. He exhibited a frame glazed on this system, and gave the particulars of some experiments which had been made, and from which it appeared that the semi-cylindrical panes sustained a smart blow with a hammer without fracture.

Mr. M. Digby Wyatt said, that the previous speakers had almost exhausted the subject, but before the discussion closed he wished to notice a few points, to which attention had been directed.

The resistance of the foundations of the more important columns had been proved, by a pressure equal to 30 tons on each, and the stiffness and general stability of the edifice had been severely tested, not only by heavy gales, but by the process of hoisting the transept ribs, during which no vibration was perceptible.

The anticipated amount of expansion and contraction was provided for in the longitudinal direction of the building, by using wooden keys, for fastening the girders into the snugs, whilst transversely, where great rigidity was essential for resisting pressure against the extended surface, and no injurious effect of expansion or contraction was anticipated, iron keys, driven quite home, were invariably employed.

As to the great amount of light in the building, he submitted that the objects exhibited would generally demand as full light as possible, and not, like pictures, to have that light thrown on them in certain directions ; but even should that be the case, it was competent for each exhibitor to make arrangements for moderating the light for his own particular purposes.

Mr. C. H. Gregory begged to direct the attention of the members to an article written by Mr. W. B. Adams, in the " Westminster and Foreign Quarterly Review," for April, 1850, in which, after examining the objects of the Industrial Exhibition, and the kinds of building desirable for it, it was suggested, that the structure should be like " a great metropolitan conservatory, the materials of which should be chiefly iron and glass," many of the details of which were given ; and further, that the building should be permanent, and be used for the purposes of " a conservatory and winter garden " when not required for industrial exhibitions.

This he believed to have been the first public suggestion for a structure of the kind now selected, as Mr. Paxton's proposition was only brought forward in the month of July, 1850.

The President remarked, that he had been nominated one of the Royal Commissioners for the Exhibition of the Works of Industry of all Nations in 1851, as President of the Institution of Civil Engineers, and not in his private capacity, or from any personal merits ; it was, therefore, on that ground that he was understood to represent the Institution in the Commission.

He should be happy, at all times, to afford any information, or facilities to the members of the Institution, which his position as a Royal Commissioner, and as Chairman of the Building Committee, enabled him to do ; but it was, obviously, not fitting for him to enter into the discussion of the particular merits, or demerits of the building, which had been so well described by Mr. Digby Wyatt, and had elicited so animated a discussion. He trusted, however, that those gentlemen, who thought the present structure insufficient, might be deceived, and that the result would prove, that every precaution had been successfully adopted, for insuring the safety and efficiency of the structure.

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BUILDING FOR THE GREAT EXHIBITION OF INDUSTRY OF ALL NATIONS IN LONDON, 1851.